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BULLETIN No. 12.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

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REPORT

ON THE

Condensation of Atmospheric Moisture.

BY

CARL BARUS.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., October 2, 1894.

SIR: I have the honor to transmit herewith a report on The Condensation of Atmospheric Moisture, by Carl Barus.

I recommend that it be published as a bulletin of this Bureau.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

HON. CHAS. W. DABNEY, JR.,
Acting Secretary of Agriculture.

290876

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PREFACE.

Following the instructions of Prof. Mark W. Harrington, it will be my purpose in the course of the present researches to trace the isothermals of water, experimentally, throughout the region of changes of physical state from liquid to vapor. By mapping out the whole of the stable contours I hope to reach definite results relative to the unstable part of their path, believing that this—the *field of collapse*, as it may be called—is of marked meteorological importance.[1] Incidentally I shall also obtain data for the law of growth of water globules, from the smallest physically appreciable dimensions to the largest attainable size, and thus supply another series of meteorological results. The subject of research considered from these two points of view may be termed the condensation problem, assuming that the stated condensation takes place in a medium of air.

Necessarily my work at the outset will consist of an investigation of promising methods, and the present bulletin contains about as much experimental evidence as I am able to adduce by the aid of the supersaturated moist air obtained from steam jets, when the results are interpreted by methods of optical interference. I make a survey of the subject in Chapter I, for changes of state in general. Chapter II follows with an account of the condensation phenomena produced by the jet method, together with their bearing in the condensation problem. Chapter III contains an application of this method to the meteorology of dust (so called). Chapters IV and V, finally, give succinct information as to the distribution of temperature met with in the jet experiments, to be used in the interpretation of Chapter II.

I had hoped to add to this bulletin certain data on the growth of water globules, to be reached by the method sketched in Chapter II, but the urgency of a change in the location of the laboratory has compelled me to break off my work at an earlier stage of progress.

My thanks are due to Prof. S. P. Langley, Maj. J. W. Powell, and Mr. Clarence King for working facilities kindly placed at my disposal, and to the Chief of the Weather Bureau, and Profs. Cleveland Abbe and Frank H. Bigelow for various points of advice.

CARL BARUS.

PHYSICAL LABORATORY,
U. S. WEATHER BUREAU, *May* 1, 1893.

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[1] Cf. Professor Harrington's paper in the Am. Meteo. Jour., IX, p. 469, 1893.

Postscript, January 28, 1895.—The present bulletin reaches my hands, now, as the mere fragment of an extensive piece of research, actively planned out over two years ago. I wish therefore to express my regret that an investigation which opened with so much promise had to be discontinued, and that during the year of my connection with the Weather Bureau a great part of my time was unavoidably taken up in first reorganizing the laboratory for meteorological research, and thereafter removing the whole of it to new quarters—an undertaking involving much labor, none of which appears in the bulletin. I wish also to express my indebtedness to the generosity of Prof. Alexander Graham Bell, without whose effective aid the reorganization would have been impossible.—C. B.

CONDENSATION OF ATMOSPHERIC MOISTURE.

CHAPTER I.

CHANGE OF PHYSICAL STATE IN GENERAL.

1. *Introductory.*—In defining my duties as a member of the Weather Bureau, Prof. Mark W. Harrington indicated that problems connected with the condensation of water from moist air were first to be considered. I was left at liberty to look at these phenomena from a general point of view, and accordingly I have commenced the study of condensation either from fusion or from vaporization, as well as from solution (liquid or gaseous). The recent theories of solution originating in the epoch making researches of Van't Hoff adduce many reasons for grouping all these phenomena under a common head.[1]

To obtain a clear notion of the principle which seems to underlie all condensations, no matter what be the nature of the change of state involved, it is expedient to go back to James Thomson's[2] interpretation of Andrews's classical measurements. Given a fixed mass of nonsaturated vapor always maintained at constant temperature in a suitable vessel of any kind. It exerts a reacting pressure on the walls of the vessel, due to molecular bombardment, and therefore depending on the volume into which the vapor has been coerced. Let the volume be decreased, temperature being kept constant, the pressure of the vapor will increase approximately, in accordance with Mariotte's law, until eventually the vapor begins to condense. From this point on the reacting pressure remains constant throughout relatively large decrements of volume until the vapor is wholly liquid. If volume be even further decreased, pressure then again increases, but at an enormously more rapid rate than before, until the liquid-solid succession of condensations is approached and passed. The phenomenon does not terminate here, for the continued decrease of volume at constant temperature implies a remote series of condensations probably chemical in their nature—and so on indefinitely. Neither does the phenomenon begin with the vapor-liquid phase. The case of gaseous dissociation need only be considered in the inverse order to be a condensation phenomenon, which, in its turn, follows a series of analogous cases.[3]

---

[1] Cf. Blümcke: Zeits. f. phys. chem. VI, p. 153, 1890; VIII, p. 554, 1891; IX, p. 722, 1892.

[2] James Thomson: Phil. Mag. (4), XLIII, p. 227, 1872.

[3] Cf. Barus: Am. Jour. Sci., XLII, p. 147, 1891; also Am. Chem. Jour., XIV, p. 191, 1892.

2. *Vapor condensation.*—To fix the ideas, however, it is well to restrict all remarks to vapor-liquid condensation, the successive steps of which have just been described. They are three in number and involve three apparently wholly disconnected laws. So complex a state of affairs is remarkable, and, from the rarity of true discontinuity in physical phenomena, one would be inclined to take exception to the completeness of the experiments by which these laws are deduced, even if no other evidence were forthcoming. Direct evidence, however, is available in abundance, seeing that a whole class of occurrences, such as supersaturation, retarded ebullition, etc., are ignored by the laws. The question thus accentuates the need of a method by which the volume changes of liquids may be coordinated with the volume changes of vapors by a law which shall suffer no break of continuity during the intermediate stage. This is what James Thomson did by postulating his well-known doubly inflected isothermals.

If, as is frequently advantageous, names are to be given to the two species of isothermals described, the discontinuous set may be called empiric, since they are most usually observed. The other, or the continuous set of Thomson, may be called normal or theoretic, for they were arrived at by induction.

Thus there are two limiting cases in relation to which isothermal condensation may be conceived to take place. In the first of these condensation is always kept at a maximum by foreign interference—for instance, by the capillary forces at the surfaces of contact between vapor and solid. If, throughout all the volume changes, sufficient time be allowed, the empiric isothermals, though broken in the manner specified, are none the less definite in character and position. The other limiting case is that in which pure vapor, perfectly free from foreign influences (i. e., out of all contact with solids and liquids), is brought to condense as a whole by some ideal means. The isothermals of this normal case are the doubly inflected lines without break of continuity, also specified. They also must be perfectly definite.

In the annexed diagram (fig. 1), let v be the axis of volumes, and let p be the axis of the reacting pressures. Temperature being always kept constant, let $a\,b\,c\,d\,e\,f$ be the (normal) isothermal, for condensation out of all contact of the vapor with solids or with liquids, and let $a\,b\,g\,e\,f$ be the isothermal for a virtually perfect contact of the vapor with plane surfaces of a solid or a liquid. For this case p_2 is the ordinary vapor tension.

The important question now arises, Are there no other isothermals corresponding to the given temperature except the two extreme examples mentioned? The answer to this question brings us face to face with the thermodynamic interpretation of certain capillary phenomena. It is needless, however, to enter the subject here, further than to state that vapor tension increases with the curvature of the liquid surface, other things remaining the same. Now, as condensation (supposing pressure or volume of suitable magnitude) must necessarily begin at some physical point or points within the volume of free vapor, the largest points will obviously be first selected; but in pure vapor none of the possible points can exceed the vapor molecule in size. Consequently at the point *c* of the diagram the reacting pressure p_3 of pure vapor can not exceed the vapor tension at a convex surface of molecular dimensions.

Something similar applies to the point *d*, or to the minimum pressure p_1, at which the liquid is stable at the given temperature. But the physical interpretation of the state of things here is not at hand. Suffice it to say that, for thermodynamic reasons (since *b*, *c*, *g*, *d*, *e*, *g*, *b* is a reversible isothermal cycle), the area *b*, *c*, *g*, *b* must be equal to the area *g*, *d*, *e*, *g*. In accordance with this condition *d* is located. (Cf. Preface.)

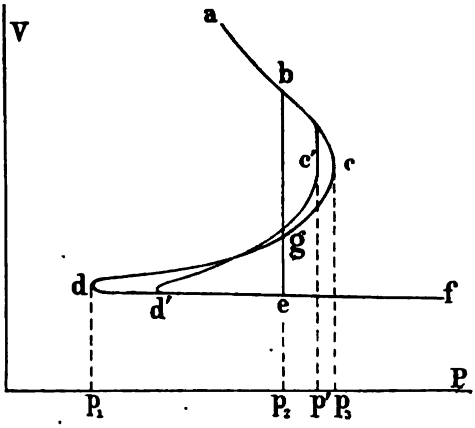

Fig. 1.—Diagram of isotherms.

Suppose, however, that an indefinite number of uniformly small solid nuclei be disseminated throughout the vapor, which is otherwise quite out of contact with either solids or liquids. Let the size of the nuclei be such that the vapor tension at their convex (spherical) surfaces, if liquid, and at the given temperature, would have some value p^1 between p_2 and p_3. Then the point *c* (since it could not be reached) would be replaced by same point c^1, and the new isothermal may be represented by same line $b\ c^1\ d^1\ e\ f$. In other words, between the extreme cases, *a b c d e f* and *a b g e f* an infinite number of isothermals may be conceived to exist at the same temperature, each of which corresponds to a definite size of the solid nuclei uniformly distributed throughout the volume of vapor. Under the term solid, as applied to the nuclei, nothing more is to be inferred than that they persist. Nor need any reference here be made to electrical or other methods for precipitating condensation.

3. *Meteorological isothermals.*—Aside from the presence of air, it is obvious that an isothermal of the form *a*, *b*, *g*, *e*, *f* can not apply to the free

atmosphere, seeing that condensation takes place there out of contact with massive solids. Neither can the normal isothermal *a c d e f* be applicable in the meteorological case; for the atmosphere invariably carries a burden of excessively fine "dust" as one of its essential constituents. Hence lines such as *a b* c^1 d^1 *e f* (or their equivalent isopiestics) must meet the atmospheric conditions, and the points *c* and c^1 will tend to coincide in proportion as the dust is of a finer quality.

Now, it is a matter of special meteorological significance that, whereas along the path *a b c* the vapor is stable and along *d e f* the liquid is stable, the path *c d* is essentially unstable. For along *c d* the reacting pressure decreases when the volume decreases, and hence this path is one of pronounced *collapse.* It is to be noted, too, that the double inflection, which is here exhibited only for the isothermals, will be a characteristic feature in any thermodynamic surface and will therefore, in general, affect the isopiestics or the adiabatics or any other order of lines drawn upon such a surface. Nor can the presence of air do more than modify the phenomenon in such a way as not to wipe out the tendency of the vapor to collapse as a whole when the proper pressure and temperature conditions are satisfied.

4. *Liquid-solid condensation.*—It is obviously very difficult to map out a concrete case of the true isothermals for the change of state from gas to liquid, and I am not aware that this has been done except in an inferential way. One may, for instance, use the intrinsic equations due to Clausius or to Van der Waals and compute the unstable contours; but this, for the time being, is an exterpolation throughout the whole meteorologic issue. For the change of state from liquid to solid, however, such representation is feasible, as it appears that the surface forces at the walls of the vessels here dwindle to smaller significance, though I am far from asserting that they are negligible. A totally distinct order of difficulties is now introduced, owing to the fact that enormous pressures are needed to bring out the details of condensation; and it is for this reason probably that the stated surface forces are of less consequence.

The only concrete example of the condensation from liquid to solid which has thus far been adduced is contained in my work on the isothermals of naphthalene. I shall reproduce its main features, with certain modifications of method here, because of its significant bearing on the general problem under consideration. The chart, fig. 2, which is one of the several series of data obtained, is laid out on a plan similar to the preceding figure, 1, the axis of volume (cubic centimeters) being vertical and the axis of pressure (atmospheres) horizontal. Naphthalene melts at about 80° C., so that the isothermals (the constant temperature of each of which is added at the two ends of the curve) above 80° begin with liquid naphthalene, those below 80° with solid naphthalene. Five distinct isothermals (63°, 83°, 90°, 100°, 130°) are shown, and the observational points on each of them marked. It is a difficult matter in work of this kind to quite eliminate the thermal discrepancy, for a liquid on freezing gives out heat, and on melting it absorbs heat. The free heat (positive or negative) thus available may be productive of distorting volume changes of no insignificant amount, and hence it is necessary to wait long enough until the heat error is dissipated. For this reason the time (in minutes) at which each observation is made is also stated on the curves by numerals referring to the points. The method of work was cyclic—i. e., starting with the liquid at a given fixed temperature, pressure was increased in successive relatively

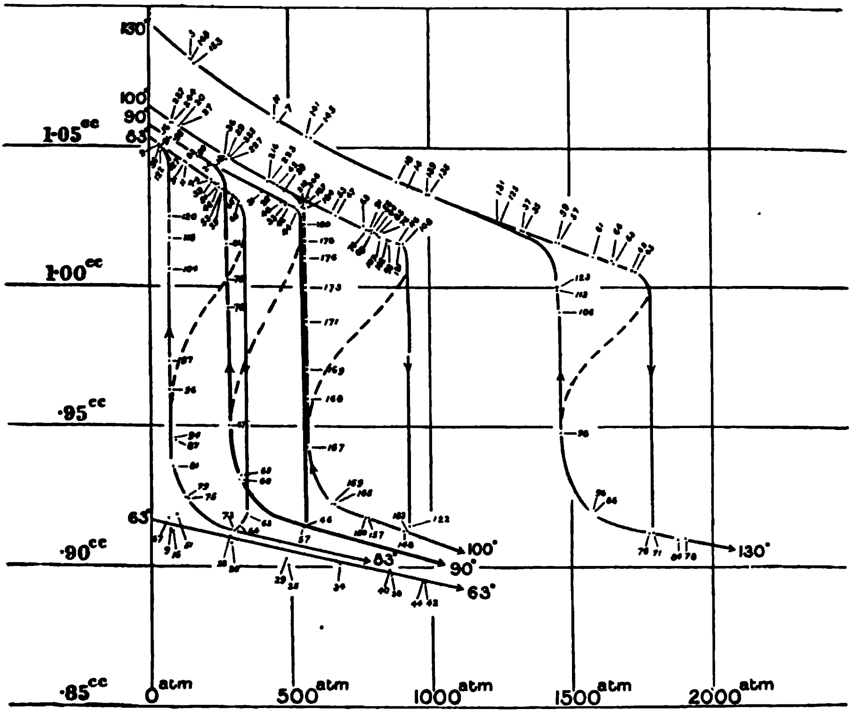

FIG. 2.—Fusion isotherms of naphthalene.

small steps until solidification ensued, and thereafter pressure was usually increased somewhat further to insure complete freezing. After this, pressure was in like manner reduced in successive small steps, care being taken to pass very slowly through the period of melting, until eventually the initial pressure (practically zero) was again reached. Arrows are added to the cyclic parts of the curves, showing their drift, and the individual observations (whether belonging to the pressure-increasing or pressure-decreasing part of the march) can be further identified by consulting the times at which they were severally made.

5. *James Thomson's inflections.*—The chief information to be obtained from these curves, so far as the present purposes go, lies in the difference of pressures under which, at a given temperature, freezing and melting respectively take place. Thus it takes a decidedly greater pressure to coerce liquid naphthalene at 100° from the liquid to the solid state, than the pressure at which solid naphthalene at the same temperature freely melts. The same fact is corroborated by all the other isothermals, and is a law inherent in the phenomenon. Here therefore is direct evidence of the occurrence of James Thomson's doubly inflected cycles. I have indicated their probable contours throughout by the dotted lines contained within each cycle. The only question to be answered is the reason why the dotted lines (theoretic isothermals, from which the empiric isothermals can only be obtained inferentially, as in section 9) were not actually observed instead of the cycles. The sufficient explanation of this is the method of work, for the volume changes which are measured at the end of each step in pressure do not react on this pressure. These volume changes are merely such as actually occur when the pressure of the medium is sustained and momentarily invariable. In other words, the pressure measured is *not* the reacting pressure of this sample of naphthalene, and it is this (reacting) pressure only to which the doubly inflected curves apply. On the other hand, however, the initial or stable contours of these curves (*a*, *b*, *c* and *d*, *e*, *f*, in fig. 1) should be visible in the chart (fig. 2), and they actually are. Thus in the isothermal for 83°, at 60 and 63 minutes, curvature is distinctly (more so in the numerical data) indicated on the verge of the passage from liquid to solid, although as a rule this path is precipitous. Curvature is, however, always pronounced, and clearly so, in the change from solid to liquid, such as occurs, for instance, after 73 to 97 minutes on the same isothermal (83°), or on any of the others. The magnitude of this cyclic change, or hysteresis, is particularly remarkable. At 100°, for instance, the difference between the freezing and melting pressures amounts to over 350 atmospheres; and this for the case of a body which, like liquid naphthalene, does not easily admit of being cooled below its melting point without solidifying. Whether the pressure difference would be increased if solidification took place in a free liquid—i. e., in one which is not in contact with solids, and quite without nuclei—has not been evidenced.

6. *The two critical points.*—Another equally marked analogy between the gas-liquid and liquid-solid condensations is the occurrence of a critical point in each case. The former has long since been pointed out and is now known for a great number of volatile bodies, including steam. The occurrence of a critical point in liquid-solid condensations may be reasonably inferred from the chart, fig. 2, seeing that the vertical height of the cycles continually decreases when higher pressures and temperatures are approached. Eventually, therefore, one must reach a thermal state for which the liquid changes isothermally into the solid without marked or sudden change of volume, and beyond which the isothermals will probably be even without inflections. Other deductions may be made from the figure, but, as they have no meteorologic bearing, I will omit them.

7. *Isothermals of solution.*—In view of the detailed analogy which holds between many characters of fusion and of solution, much that

can be investigated for the simpler of these phenomena (fusion apparently) will be applicable to the other. A substance may be transferred from the solid to the liquid state either (1) by heating it or (2) by dissolving it. In general, excess of temperature or of solvent favor the diminution of viscosity here in question. A liquid on the verge of solidification or a concentrated solution is solidified or deposits solid on cooling or on the withdrawal of the solvent. In both cases the nice adjustment of molecular equilibrium is accompanied by volume hysteresis, under cooling in one case and supersaturation in the other. Hence I concluded that if under proper thermal conditions pressure alone can solidify a liquid, it can also, under proper solutional conditions, induce crystallization or the deposit of solid from solution.

Inasmuch as the preceding paragraphs show that the isothermals expressing the nature of the condensation of a gas have a complete counterpart in the isothermals expressing the solidification of a liquid, it follows that similar parallelisms will probably be manifest in the behavior of liquid and of gaseous solutions. Now, it is the latter case which forms one of the chief concerns of meteorology, since water condenses out of air and evaporates into air, so that air and moisture make up a solutional system. Having, therefore, the apparatus with which the above fusions were studied still at hand, it did not seem ill-advised to begin the meteorological work by investigating the conditions under which a solid is precipitated from solution. Presumably, as before, the cyclic changes would be more sharply demonstrable for this case than for gaseous solutions.

Having used the term molecular or chemical equilibrium, I must indicate its direct relation to the mechanism of a vapor tension. Whenever one part of a complex body passes from a first to a second molecular state as fast as the other part of the body passes from the second to the first state, then there is molecular equilibrium at the interface. Thus in a closed vessel water ceases to evaporate when as many molecules are rejected by the liquid as it receives from the gas.

In carrying out the work for the isothermals of solution, two serious difficulties presented themselves. The first is due to gravitational separation. Whenever the dissolved solid is solidified at a given temperature by pressure, the precipitate tends to fall to the bottom of the tube. After relieving the pressure the original solution can not be reproduced, for the solid contained in the bottom of the tube can only reach the top by the excessively slow process of diffusion. As the result of a large number of compressions, therefore, the lower layers are soon more than concentrated and contain excess of solid, while the upper layers are relatively dilute. The measurements, therefore, become exceedingly difficult of interpretation, for there is no guaranty that the solution treated is ever homogeneous. The only way of overcoming this irregularity which occurs to me would consist in dissolving the solid in a gelatinous menstruum, in which case, however, the menstruum itself must be separately investigated. The second difficulty encountered is the small amount of volume change which accompanies precipitation. It is only a fractional part of the liquid solution (and not the whole, as in case of fusion) which undergoes change of state. The preliminary problem therefore is the selection of bodies which not only show the largest contraction, but which at the same time are remarkably soluble; but very soluble solids as a rule show hysteresis or cycles of such an enormous extent that the available pressures are powerless to solidify them in the absence of crystalline nuclei. In short, my work on the isothermals of solutions, although carried through an interval of 2,000 atmospheres, has not led to clear-cut data, and I will therefore reject the whole of it excepting only a few illustrative results obtainable by compressing threads of liquid contained in capillary tubes.

8. *Data for liquid solutions.*—The following table contains results for the apparent compressibility of naphthalene dissolved in toluol. A thread of the solution was compressed between terminal threads of mercury, under conditions of constant temperature, θ; and the compressibility (β) is estimated in terms of the change of length of the thread of solution. The table contains the time (in minutes) at which the individual readings for pressure and for volume decrement $\left(\frac{v}{V}\right)$ were taken. Two cases are given. In the first of these a few crystalline nuclei were always present in the (turbid) thread; in the other the solution was clear and without nuclei.

TABLE 1.—*Isothermal behavior of a solution of naphthalene, concentrated at 29°, in toluol. Initial length of thread 9.85cm at 30°.*

[Treatment in capillary tubes.]

Turbid solution: $\theta = 30.1°$ (29.7°—30.6°).				Clear solution: $\theta = 31.0°$ (31.8°—31.5°).			
Time.	Pressure	$10^4\times\frac{v}{V}$	$\beta\times10^6$.	Time.	Pressure.	$10^4\times\frac{v}{V}$	$\beta\times10^6$.
45	30	0	....	20	43	0	....
46	112	91	111	25	119	61	80
50	110	91	114	32	117	71	96
52	177	173	120	34	242	183	92
55	173	163	115	40	234	183	96
57[1]	273	305	125	42	348	284	93
60[1]	264	325	140	48	340	284	96
75[1]	261	376	165	50	471	386	90
80[1]	259	386	....	60	459	386	93
85[2]	183	264	....	62	462	315	....
92[2]	191	264	....	65	463	315	....
95[3]	99	142	....	69	225	203	....
104[3]	104	142	....	85	230	213	....
109	22	61	....	97	61	51	....
120	25	61	....	101	62	51	....
123	170	244	125	105	480	407	85
135	157	213	120	112	459	396	87
139	201	274	120	120	456	406	90
150	198	274	125				
160[1]	255	366	130				
167[1]	252	366	135				
175[1]	252	366	135				
	296	508	165				
180[2]	160	295	....				
	0	61	....				

Tube breaks at 650 atmospheres. No freezing.

[1] Freezing. [2] Solution. [3] Flocules.

The results of this table are given in the chart, figs. 3 and 4. Straight lines connect the individual observations and arrows show the directions in which pressure varies. Points belonging to different cycles are distinguished by little circles. The volume decrements (ordinates) corresponding to each pressure (abscissas) are represented positively. Numerals show the times at which the observations were taken.

Considering the turbid solution first, the compressibility is regular between 45 and 57 minutes. Between this and 80 minutes partial solidification has set in with a shifting of the fiducial zero, both because some of the dissolved solid is thrown out permanently and because the mercury thread has been parted in the endeavor to actuate the solidified thread. When pressure is reduced, the compressibility is again regular. Finally the second cycle resembles the first in most respects. Throughout the work the mean apparent compressibility exceeds $\beta = 0.000110$. It is usually much larger, particularly when the solidification occurs.

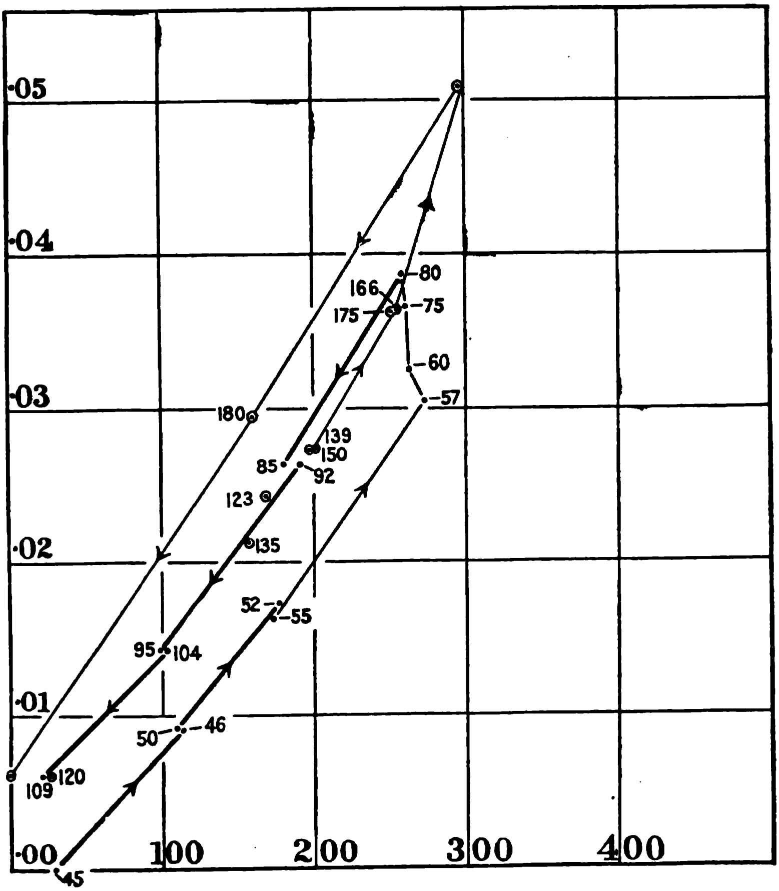

Fig. 3.—Isothermal behavior of a turbid solution of naphthalene in toluol.

Fig. 4 for the clear solution shows a shifting of the fiducial zero, due to separations of the mercury thread. Otherwise the results are fairly regular. In one important particular these results differ from fig. 3, namely, that the mean apparent compressibilities for the clear column are always smaller than $\beta=0.000\,096$. Indeed, for the turbid column the compressibility actually increases from about 0.000 120 to 0.000 150 as more of the solid has been thrown out; whereas in case of the clear column the average apparent compressibility[1] is about 0.000 090.

The reasons for this difference of behavior are not for to seek, but they are of great importance in relation to the present inquiry. In a solution turbid with excess of solid there is a fixed state of chemical equilibrium corresponding to each pressure. When pressure increases isothermally more solid is thrown out, and when pressure is diminished the solid is, so far as possible, redissolved. The "turbid" isothermals are therefore necessarily empiric. This change of state is therefore equivalent to an increased rate of volume decrement, and hence the observed apparent compressibility is abnormally large as compared with the same solution free from crystalline nuclei. "Clear" isothermals are thus essentially normal or theoretic. The results here given are therefore identical in kind with the data found and interpreted for silicate

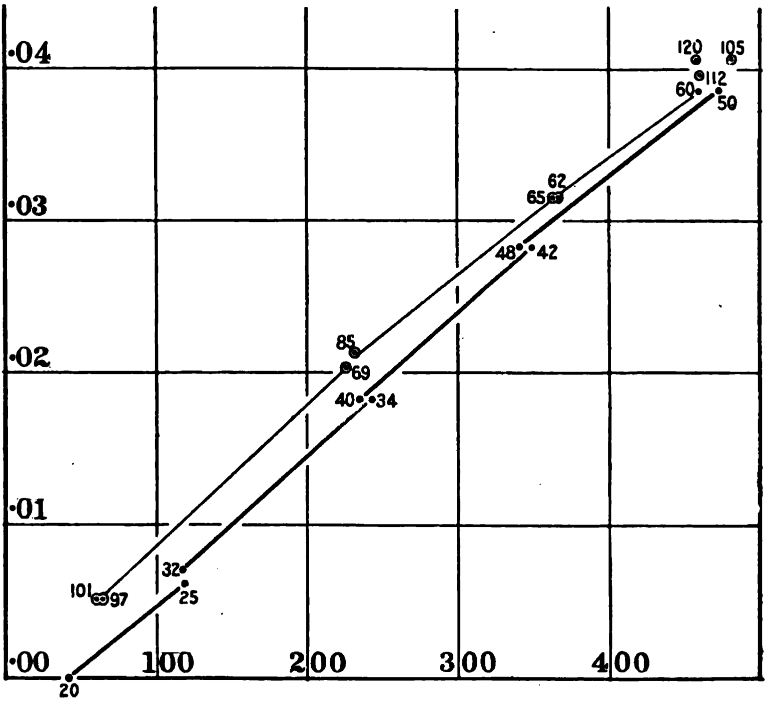

Fig. 4.—Isothermal behavior of a clear solution of naphthalene in toluol.

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[1] Since the data for compressibility were merely to be compared, there was no need of correcting for the volume expansions of the glass tube.

solutions.[1] In the latter instance I was able to increase the solid in solution regularly and obtained an equally regular increase of compressibility to correspond with the amount of available solid. So marked were the results that the final compressibility was fully three times the initial compressibility at the same temperature, whereas the usual effect of clear solution is a marked decrease of compressibility.

The second important result contained in Table 1 is the absence of solidification in case of the clear column, even when pressures very much larger than those applied to the turbid column were brought to bear at nearly the same temperature. Here, therefore, is indisputable evidence in favor of a solutional cycle, or of solutional hysteresis, of the same kind though much larger in magnitude than was found for fusion.

In the following table I add corroborative results for a solution of zinc sulphate, concentrated at about 40° and then cooled down to 10°. *R* denotes the resistance of a filament of the solution varying in length with the volume decrement due to compression. From this and the volume of the reservoir the total isothermal volume was computed for each pressure.

TABLE 2.—*Isothermal behavior at 10° of an aqueous solution of zinc sulphate, concentrated at 40°.*

Time.	Pressure.	*R*.	Volume.
0	100	12, 200	0. 7329
15	298	12, 500	. 7314
23	550	12, 700	. 7299
34	899	12, 800	. 7289
47	1, 255	13, 000	. 7371
57	1, 798	13, 400	. 7244
60–75	2, 038	(*a*)	....

a Broken. On removing from piezometer, the solution is clear, showing absence of solidification. Compressibility too small for measurement.

Thus the striking fact is brought out that the solution, already cooled 30° below its saturation temperature, is capable of withstanding at least 2,000 atmospheres without solidifying. The experiment could have been made even more striking by cooling the solution down to a lower temperature. Another result of the table is the low apparent compressibility obtained for the solution, as compared with pure water. Had there been floccules of salt present the compressibility would have been larger than for that of water for reasons already stated.

To summarize therefore, the chief feature of the results relative to the isothermals of solutions is the occurrence of a pronounced volume lag, in virtue of which solution at a given temperature takes place at a lower pressure than the corresponding precipitation. When precipitation eventually does occur it is partial, and in this respect the present behavior differs from the corresponding case of freezing from fusion.

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[1] Barus: Am. Jour., XLI, p. 110–116, 1891.

In other words, the solution phenomena contains a clear-cut example of chemical equilibrium varying with temperature and with pressure, the meteorological bearing of which will already be manifest in the course of the following paragraphs.

9. *Blümcke's deductions.*—Questions relating to the thermodynamics of mixtures or solutions have been treated with great generality by Van der Waals[1] and others. Blümcke's[2] geometrical constructions, however, afford a clearer view of the matter, when the isothermals of mixed substances are to be considered. I will therefore reproduce a typical case of his results here. Given two coercible gases, which in their liquid state are perfectly miscible, let the thermal state of each lie below its critical temperature.

In the annexed diagram, fig. 5, let P, V, X be the axes of pressure, volume, and composition, respectively. If the mass be always a unit, then for $X=0$, the mixture will consist of one of the substances and for $X=1$ of the other of the substances, exclusively. Hence in the diagram, *n g o p r s* may represent the theoretical, *n g z r s* the empiric, isotherms of the first body, and *a b c d f* the theoretical, *a b u e f* the empiric, isotherm of the second body; so that *g* and *b* are the points of incipient, *e* and *r* the points of completed, liquifaction of the two bodies, at the same temperature. But equally definite points of incipient and completed condensation exist for each of the infinite number of mixtures of the two bodies; or, in other words, there is a curve, *g i b*, in space at which nuclear condensation begins, and a corresponding curve, *r m e*, at which it is complete. These two curves belong simultaneously to the theoretic and to the empiric isothermal surfaces.

The empiric surface (*r z g i b u e m*) is a conoid so circumstanced that any sectional plane parallel to $X\ V$ (and therefore a plane of constant pressure) cuts the conoid in a straight line. In other words, the conoid is generated by a straight line moving so as to be always parallel to the plane $X\ V$, while the ends of the line travel on the space curves *r m e* and *g i b* respectively.

To find the isothermals corresponding to a given composition, x, a plane must be passed parallel to $P\ V$, at the stated distance x from it, and the lines of intersection with the surface will represent both the theoretic and empiric isotherms for the mixture. The figure contains a section of this kind about midway between the end planes ($x=0$ and $x=1$). The two isothermals are shown at *h i t v j k* and at *h i v m k*. Now, it is clear at once that the empiric isotherm *i v m* will, in general, intersect a number of the generatrices of the conoid. Hence *i v m* must be a curved line, such that pressure continually increases while volume diminishes, if the path *i v m* is to be stable, as it actually is. Finally the thermodynamic relation of the two isotherms *i t v j m* and *i v m* implies that equal areas *i t v* and *v j m* are thus intercepted.

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[1] Van der Waals: Ostwald Zts., v, p. 133, 1890.

[2] Blümcke: loc. cit.

When temperature increases, the form of the thermodynamic surface will also change. Thus if one of the ingredients of the mixture be at or above the critical temperature, the corresponding part of the isothermal surface will be more and more without double inflection, and the isothermal sections will be correspondingly modified throughout the surface. This is the case for water vapor suspended in the atmosphere, to which detailed consideration will be given in the course of development of the present investigation. Here it is merely necessary to point out the application of the surface, fig. 5, to the case of the solid-liquid solutions contained in tables 1 and 2.

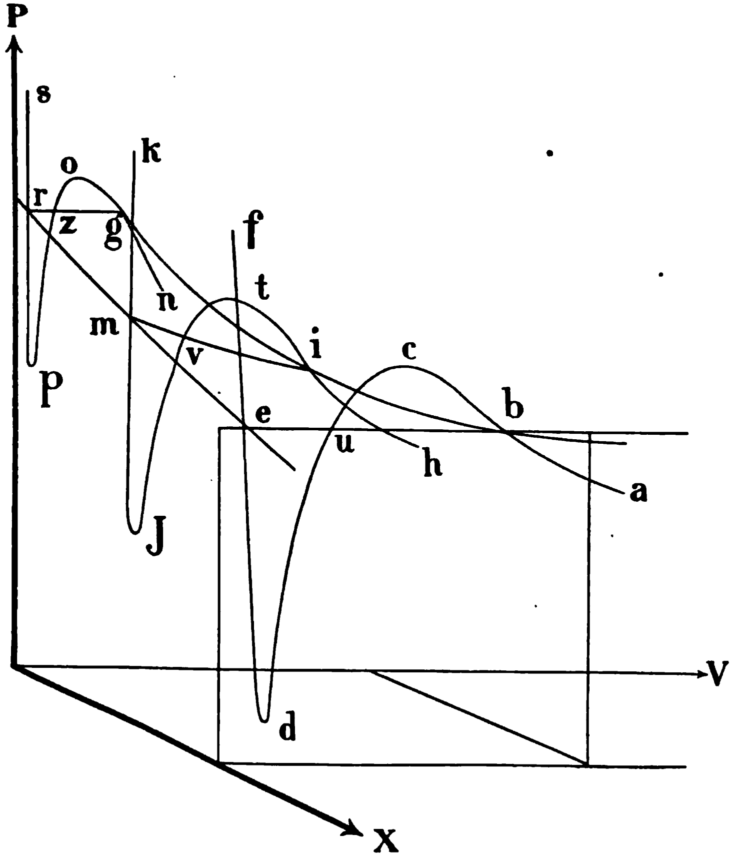

Fig. 5.—Isotherms of mixtures.

Both ingredients of the solution (naphthaline and toluol, for instance) lie below their respective liquid-solid critical temperatures. Hence the isothermals for $x=0$ and $x=1$ will have the general form instanced in fig. 5. So long, moreover, as the remarks are restricted to the precipitation of one only of the ingredients out of the solution, the character of fig. 5 need not be modified. Hence $h\ i\ t\ v\ j\ m\ k$ may be taken as the theoretic or normal isothermal along which compression is directed for the case of the clear solution, and *h i v m k* as the path of compression for the turbid solution. In short, therefore, compressibility, regarded as the rate at which volume changes with pressure, will be in a marked degree greater along the path *i t* than along the path *i v*, and this is precisely the dictum of the results contained both in tables 1 and 2.

CHAPTER II.

THE COLORS OF CLOUDY CONDENSATION.

10. *Purposes specified.*—Turning now to the subject proper of the present research—the passage from water vapor to liquid in a menstruum of air—it follows, from what has been stated, that as one can not work with free air, the method applicable to the condensation problem must be so chosen as to trace the progress of the experiment at each moment throughout the course of the change of physical state. Only by producing instantaneous condensation can the conditions of a free atmosphere be simulated experimentally, and a phenomenon, independent of the surface forces at the walls of the vessel, be observed. Above all things it is therefore necessary to obtain some means of discriminating between vapor and a collection of indefinitely small water globules. Thus, for instance, the difference of specific inductive capacity for the two cases might furnish an available criterion; but this method would present great experimental difficulties. Nor is it clear whether any inkling could thus be obtained relative to the size of the water globules. Both these desiderata are supplied within certain limits by the colors of cloudy condensation, and it is to the description of a method of producing them at will, of interpreting color in terms of size of particle, and of making the phenomenon tributary to the problem in question, that the present chapter will be devoted. If these elusive color effects can be brought thoroughly under control, then an experimental method of much greater scope than the earlier observers have appreciated must necessarily result.

Incidentally I will add other allied experiments—such, for instance, as relate to electrification, etc.

11. *Literature on cloudy condensation.*—For information on the present status of the subject, I am here as elsewhere greatly indebted to Prof. Cleveland Abbe, who, with his usual courtesy, placed his detailed knowledge wholly at my disposal.

The fundamental researches of Coulier[1] and Mascart,[2] and of Aitken,[3] though closely allied with the present work, refer chiefly to the function of dust. They are, moreover, too well known to need comment here.

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[1] Coulier: Jour. de Pharm. et de Chim. (4), XXII, p. 165, 1875; Cf. Fortschritte der Physik, XXXI, pp. 471, 870.

[2] Mascart (see Coulier) verified Coulier's work.

[3] Aitken: Nature, XXIII, pp. 195, 384, 1880; Trans. Roy. Soc. Edin., XXX, p. 337, 1881.

With regard to the color phenomena, the first definite observations were made by Forbes,[1] who worked with immense high-pressure steam jets. For this reason, probably, he saw only the yellow-browns of the first order.

The systematic research of the subject followed at a much later date, and is due to Kiessling[2]. His treatment is exceptionally thorough and virtually contains all that is known of the color phenomena by exhaustion. I shall have occasion to refer to these experiments again, and here merely state that neither the original tubular form nor the later spherical form of Kiessling's apparatus is suitable for my purposes. The condensations produced by suddenly expanding dusty air (partial exhaustion) and the colors thus evoked, however startling, are necessarily fleeting and can not be brought under control.

The subject is next taken up by R. v. Helmholtz,[3] chiefly with the object of developing a new method for measuring the depression of vapor tension produced by solution. The function of dust is considered incidentally at some length, and a size is assigned to the cloudy particles. Color phenomena are not specially observed until in a second paper R. v. Helmholtz[4] corroborates Kiessling's researches by the aid of steam jets, and particularly with reference to the condensation induced by electric discharges. He analyzes the opaque steam jet into zones of color, obtaining a serviceable scale. After a series of striking experiments, v. Helmholtz concludes that a disturbance of the chemical equilibrium of the surrounding medium produces a condensation effect on the jet similar to the dust effect. Omitting further reference to this important research for the present, I shall proceed with the corroborative paper of Bidwell's.[5] He suggests that the occurrence of an opaque jet is due to electrical influences similar to those by which Lord Rayleigh[6] produced a coalescence of scattering water jets. Hence Bidwell believes the particles of an opaque steam jet to be larger than the corresponding particles in ordinary jets.

In the recent paper on the subject, Mr. J. Aitken[7] argues very soundly that Bidwell's view can not be correct, and thus substantially corroborates R. v. Helmholtz,[1] who had proved the occurrence of smaller particles in the opaque jet as compared with the ordinary jet some five years before. After classifying the various methods[2] by which the appearance of a steam jet may be made to pass from the ordinary to the abnormal aspect, Mr. Aitken discusses the causes underlying each experiment in detail. An important novelty, namely, the effect of the temperature of the medium surrounding the jet, is here introduced. To explain all the phenomena, a repulsive force acting between the particles below a certain temperature is postulated in addition to the repulsive action of the electrically charged particles. In the second part of his paper Mr. Aitken takes up the colors of cloudy condensation and gains an advantage by passing the steam jet through tubes illuminated by transmitted light. Unfortunately he does not perfect this arrangement, but proceeds to produce these phenomena by the exhaustion method, virtually repeating Kiessling's work; but the breadth and thoroughness of Mr. Aitken's work, together with the fact that it was done quite independently of the German researches, enhances the value of its bearing on the present subject.

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[1] Forbes: Phil. Mag. (3), xiv, pp. 121, 419, 1839; ibid. (3), xvi, p. 102, 1840.

[2] Kiessling: Naturw. Verein, Hamburg-Altona, viii (1), 1884; Gœttinger Nachr., v, p. 122, 1884; "Dæmmerungserscheinungen, Chapter v, pp. 133-145, Hamburg, L. Voss, 1888.

[3] R. v. Helmholtz: Wied. Ann., xxvii, p. 508, 1886.

[4] R. v. Helmholtz: Wied Ann., xxxii, p. 1, 1887.

[5] Bidwell: Electrician, xxiv., p. 146, 1889; Phil. Mag. (5), xxix, p. 158, 1890.

[6] Rayleigh: Proc. Roy. Soc. Lond., xxviii, p. 406, 1879. According to G. Wiedemann (Beiblætter), xiv, p. 291, 1890, and Wiedemann's Electricitæt, i, p. 27, these phenomena were observed by Father Gordon, of Erfurt, about one hundred and forty years ago. They were frequently repeated by Fuchs in 1856 and studied by Beetz in 1871.

[7] Aitken: Proc. Roy. Soc., li., March, 1892, p. 408.

This hasty survey will suffice for the present, as more specific information is to be brought forward in the course of the following paragraphs. I have omitted references to atmospheric phenomena, such, for instance, as are discussed by Kiessling loc. cit., and Abbe,[3] because they do not fall within the limits of the present paper.

[Among recent contributions I may refer to a discussion between Mr. Aitken, Mr. Bidwell, and myself in Nature, XLIX, pp. 340, 363, 388, 1894, as to causes which induce aqueous condensation; and particularly to a paper by E. Kaiser in Wied. Ann., LIII, p. 667, 1894, who shows that the coalescence of liquids due to electrification is the result of purely mechanical pressure. This new result effectually clinches the argument made in section 26 of this Bulletin.—January 30, 1895.]

12. *Literature on disgregation.*—Incidentally I will have to refer to the scattering of particles from the surface of a very hot metal, as well as to the analogous phenomenon produced by an impinging beam of ultra violet light, by electrification, etc. The work which has been done

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R. v. Helmholtz: Wied. Ann., XXXII., p. 2, 1887. After referring to Kiessling's results, V. Helmholtz remarks: "Da letztere (Diffractionsfarben) von der Grösse und Regelmässigkeit der Nebeltröpfchen abhängen, so liegt der Schluss nahe, dass durch die electrischen Kräfte die Condensation * * * beschleunigt wird. Die Art, wie sich die Farben mit der Elektrisirung der Spitze ändern, scheint dies zu bestätigen. Ist nämlich die Menge der ausströmenden Elektricität sehr gross, so wird der Strahl bläulich bis tief Azurblau, wie der Himmel. Diese Färbung deutet auf sehr zahlreiche, sehr kleine, und sehr regelmässige Nebeltröpfchen hin. Lässt der Strom der Elektricität allmälich nach, so wird das Blau immer weisslicher, was auf das Hinzutreten grösserer Tropfen deutet," etc.

[2] These are: (1) Electrification of jet, (2) an increase in the number of dust nuclei, (3) cold or low temperature of the air, (4) high pressure of steam, (5) obstructions and rough nozzles. Aitken, loc. cit., p. 409, et seq.

[3] Abbe: Am. Meteo. Jour., V, p. 529, 1889.

on these subjects is, however, very extensive, so that only a mere mention[1] of prominent papers can be made here.

APPARATUS.

13. *The jet.*—To answer the requirements of section 10, the endeavor must be made to construct an apparatus by which any of the colors of cloudy condensation may be produced at pleasure, and be maintained at the greatest brilliancy possible for any length of time. In the color estimations, furthermore, it is desirable, if not necessary, to have a given normal or fiducial case of condensation constantly at hand, for comparison with the results obtained in any variation of experiment. Section 17. Only in the case of vapors issuing from a jet are the preliminary conditions filled, for here the particles are supplied as fast as they are removed out of the field of view, and they may be removed before they change in size appreciably. Section 23. The jet, moreover, may either be fed with pure steam or with compressed air supersaturated with aqueous vapor. Section 25.

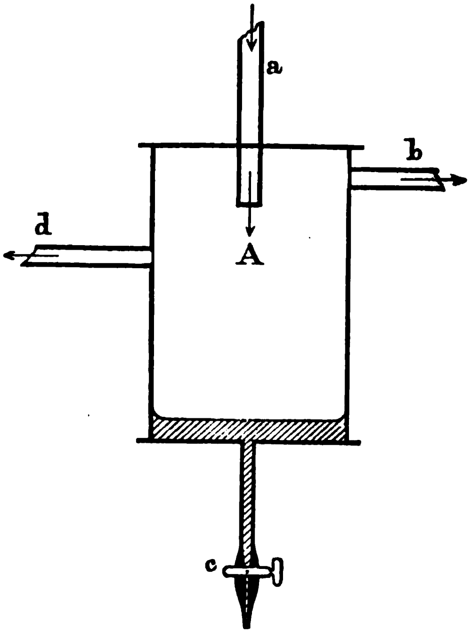

Fig. 6.—Steam box. Scale ¼.

When steam is used alone, it must be available in large quantity, at a pressure of about 1 atmosphere or more. This pressure may then be reduced by an ordinary steam cock. To dry the steam, it is conveniently passed into a cylindrical box, *A*, fig. 6, through the vertical pipe *a*, surmounted by the cock specified. It is conveyed to the jet by a lateral pipe, *b*. The water which collects is discharged from time to time through *c*, at the bottom of the box, and a pipe, *d*, communicates with an open mercury manometer for the measurement of pressure. It is often necessary to have two afflux pipes, *b*, one of which is provided with a suitable stopcock. Section 17. *A* may be made of stout tin plate, thoroughly soldered.

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[1] The reader is referred to Nahrwold: Wied. Ann., xxxi, p. 467, 1887; xxxv, p. 107, 1888. Berliner: Wied. Ann., xxxiii, p. 289, 1888. Wiedemann and Ebert: Wied. Ann., xxxiii, p. 241, 1888. Elster and Geitel: Wied. Ann., xix, p. 588, 1883; xxvi, p. 1, 1885; xxxi, p. 109, 1887. Guthrie: Phil. Mag. (4), xlvi, p. 257, 1873. Koch: Wied. Ann., xxxiii, p. 454, 1888. Kayser: Wied. Ann., xxxiv, p. 760, 1888. Hertz: Wied. Ann., xxxi, p. 983, 1887. Stoletow: C. R., cvi, p. 1149, 1888. Hallwachs: Wied. Ann., xxxiii, p. 301, 1888. Lenard and Wolf: Wied. Ann., xxxvi, p. 443, 1889. Righi: Mem. Acad., Bologna (4), ix, p. 369, 1888. Crookes: Nature, xliv, pp. 212, 455, 1891. Prof. A. W. Wright, of Yale College, investigated this subject extensively at a much earlier date.

A jet of almost any kind, with a smooth hole about 1 mm. in diameter, is satisfactory. It may be conveniently shaped from lead pipe. When the variations of the color phenomena are to be quantitatively studied, it is advisable to make the jet[1] as shown in fig. 7. Here *a b* is a brass tube about 10 cm. long and 1 cm. in diameter, the end *b* of which is threaded both on the outside and inside, so that a small thin-walled nipple, *c*, closed at the outer end, may be inserted. Into the top of *c*, a hole, *d*, is smoothly drilled. The outer thread at *b* is useful in screwing the jet to the color tube (sections 14, 16) into the center of which *c* projects. The open end *a* of the jet is to be connected with the tube *b* of the steam box, fig. 6, by a short piece of stout rubber tubing.

If this jet is so made, the diameter of the hole *d* is accurately known, and hence the quantity of steam discharged into the color tube can be computed by Napier's or Grashof's formulæ for any pressure in *A* (fig. 6). Furthermore, the amount of adiabatic cooling of the steam issuing at *d* is also easily calculated. Both of these quantities are of importance when the color phenomena are to be systematically studied.

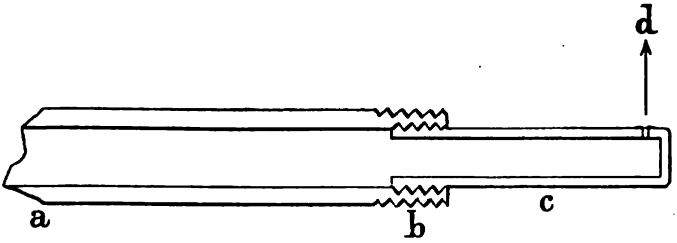

FIG. 7.—Steam jet. Full size.

Finally, by varying the number of holes in *d*, an increased intensity of some of the very faint colors, or a peculiar persistence of others, is often obtained. Section 25.

The jet is virtually a region at which steam passes suddenly from a high temperature to a relatively low temperature. A mass of steam is thus continually maintained in a definitely supersaturated condition. This state of things is accentuated by the cold air with which the jet comes in contact.

14. ***The color tube. First form.***—In making the observations the chief desideratum is a closed receptacle with a clear field of view from which all extraneous light is, so far as possible, excluded. If a tube closed with glass plates is used, these at once cloud over when exposed to steam, and the tube is then worthless for observation, except for the loudest of the colors. To look directly into steam is equally unsatisfactory, besides being a severe tax on the eyes. One way of overcoming the difficulty is to heat the plates with a Bunsen burner above 100° C. If the glass is poorly annealed a smooth piece of wire gauze may be stretched tightly over it to obviate breakage. All this is inconvenient. A special steam jacket at the plates is inefficient, while tubes open at one end would not meet the requirements of the quantitative work. Hence I proceeded as follows:

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[1] See next chapter, section 45, et seq.

The color tube is shown in its various forms in figs. 8, 9, 10, 11. In all these cases the tube proper, *C*, *A*, *A*, *B*, is the same; but it is placed in different positions to obtain different effects. This tube is preferably of thin sheet zinc or copper, to prevent rusting, and the part *A A* is about 60 cm. long and 5 to 7 cm. in diameter. A lateral branch *B*, of the same diameter and about 10 cm. long, enters the main tube at right angles, at the lower end, fig. 8, and the common bottom *m*, of the two tubes is closed by a plate of clear-glass *g*, held in place by the ring *b*

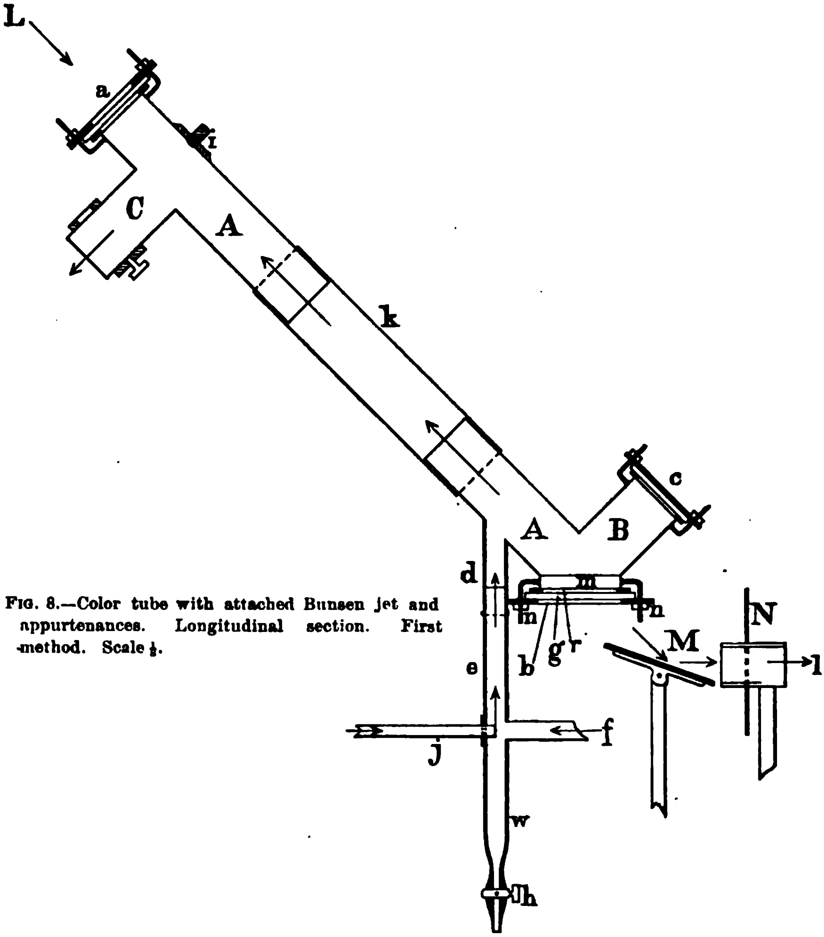

FIG. 8.—Color tube with attached Bunsen jet and appurtenances. Longitudinal section. First method. Scale ⅛.

and the nuts *n*. This joint is made quite tight by a gasket of rubber *r*, forced against the common rim of the tubes by the nuts just mentioned.

In the same way the top *a* of *A A* and the outer end *c* of B may be closed, as the figure clearly shows the efflux pipe C does not need an attachment.

The mixture of steam and air (obtained in a way presently to be shown) enters near the bottom of *A A*, through another lateral tube *d*, whose axis is in the plane *A B* and nearly vertical when the plate *g* is horizontal. The vapor, after passing through *A A*, is discharged by a large tube, *C*, near the top.

In the position of fig. 8, sky light *L* enters the tube at *a*, and, after passing through the steam and the window *g*, is conveniently observed by aid of a little mirror *M* and a screen *N*, with a circular hole in front of *M*. This device shuts off all light except the rays *l* from *a*. *B* is closed by an opaque plate. When the steam passes through *A A*, the window *a* soon clouds over but this is no great disadvantage, for *a* is a mere source of diffuse white light. The window *g*, however, must be quite transparent, otherwise the colors of the steam could not be seen. To secure this end, I poured a little water into the trough *m* at the bottom of the tube. A beautifully clear field is thus obtained, the observer looking, as it were, through a plane parallel plate of water. Additional water which collects here from the steam is eventually discharged through *d*.

The feeder in this case resembles a Bunsen burner supplied with steam instead of gas. The jet proper (shown at *j*) has the form given in fig. 7, and is screwed into the brass tube *e*, the top of which fits snugly into *d* of the color tube. Any water which collects here falls into the prolongation *w* and may be discharged through the stopcock *h*. When the jet is in action, air enters through lateral tubulures *f*, only one of which is shown in the figure.

This apparatus is frequently convenient, because the jet *j* can be so easily supplied with pure air or with air impregnated with dust or vapor in any manner. It shows a fair succession of blues and (under special treatment) intense yellows and orange browns of the first order. The field becomes quite opaque with the merest trace of dust, etc. But, as a rule, the colors are not brilliant, nor can the purples and blues of the second order be seen with certainty. I was for a long time at a loss to ascertain the cause of this, and, after spending much time on useless modifications, I finally found that the amount of air which the jet *j* can drag through the tube *E*, 2 cm. in diameter, is usually insufficient to make the colors glow. Finally, for a high pressure influx, the water in *m* is apt to become turbulent.

15. *The color tube. Second form.*—Hence I made a radical modification by discarding the old form of jet and inverting the whole arrangement in the manner shown in fig. 9. Steam now enters the tube *A A* directly by the jet *j* screwed into it near the bottom. Air is supplied through *C*, which is of the same diameter as *A A*. Moreover, *B* is now the efflux, the plate having been removed. Sky light *L*, transmitted through the tube by means of the adjustable mirror *M* and the window *a*, is observed through the inclined plate *g*. Here a difficulty presents itself, inasmuch as *g* at once clouds over; but I eventually overcame this by moistening the inside of *g* with a solution of caustic potash, applied through *B* with a sponge probang. In this way a clear field is again obtained for some time at least, after which the moistening must be renewed. The inclined position of *g* makes the whole window easily accessible, and a special hole, closed by a cork, may be cut in the elbow for inserting the probang when *B* is otherwise engaged. The tube *d* is also closed with a cork. The observer faces the plate *g* symmetrically and looks down into the color tube *A A*, while a screen, *S*, cuts off all extraneous light.

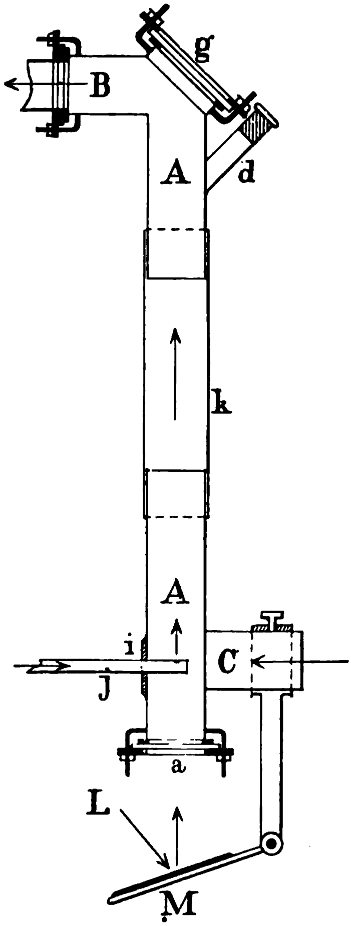

FIG. 9.—Color tube with attached jet. Longitudinal section. Second method. Scale ⅛.

With this apparatus a brilliant field of color is obtained so that minute differences may be detected, and I thus investigated the scale given below (section 18) between the intense oranges of the first order and the final greens of the second order, after which the colors are too faint for recognition. In the latter case, since low pressure steam must be employed, an advantage is secured by drilling three or five holes in the jet *j*.

Fig. 9 shows that the tubes *A A* slide into a snugly fitting envelope *k*. The system may, therefore, be shortened for observing very intense colors, or lengthened for faint colors. Section 25. Either end of *A A* may also be rotated, which in many experiments is necessary. Section 23.

16. *Illumination by reflection.*—In order to ascertain the source of color in these experiments, it is desirable to test the cloudy condensation by reflected light as well as by transmitted light. This may be done by placing the color tube, as shown in fig. 10, where the steam from the Bunsen jet enters at *d* and passes out at *C*, as in fig. 8. The plate *a* is now made opaque and the plate *c* clear, while the plate *g* is replaced by a mirror, reflecting upward, and which has a little of the amalgam scraped away from the lower surface. Hence an observer, regarding the tube from below, may look in the direction of the axis *A A* upward. The mirror *M* and screen *N* of fig. 8 may also be used. Fig. 10 shows that sky light *L* now enters through *c* and is reflected by *g* parallel to the axis of the tube, a condition which may be tested by temporarily opening *a*. If the inside of the tube is painted dark, no light can reach the eye except in so far as it is reflected (*l*) from the cloudy particles introduced into *A A* through *d*.

A plate of water, *m*, above *g*, is necessary here, as in fig. 8, to obviate clouding.

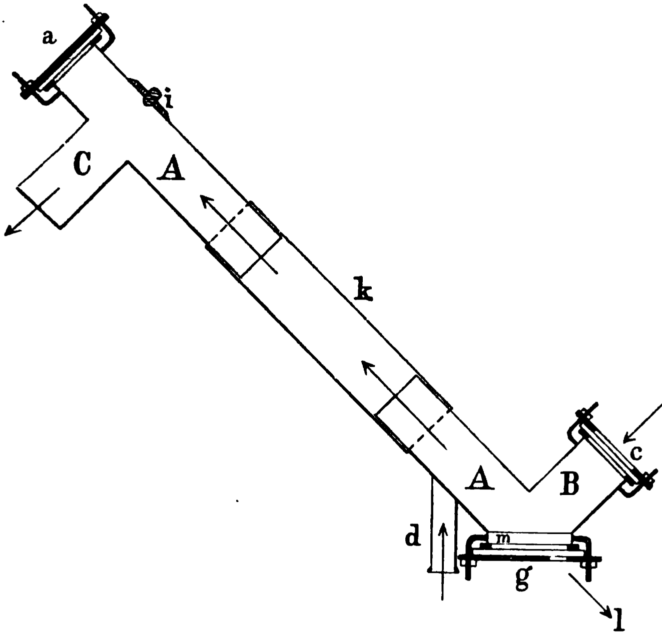

Fig. 10.—Color tube arranged for reflection. Scale ⅛.

A similar result can be secured by introducing a little mirror on a stem through *C* in fig. 9 and shutting off the light at the top of the tube. An observer looking into *C* may then view the color effects along the axis of *A A*.

17. *Differential apparatus.*—Color tests are not as a rule satisfactory for quantitative work, unless some fiducial field of color is always at hand for comparison. For this reason the apparatus (fig. 9) was further improved, as shown in fig. 11, in front view. The parts are lettered as above. Fig. 11, therefore, consists of two color tubes, identical in every respect and admitting of an independent use of both eyes. Sky light is introduced by the mirrors *M M'*. The observer looks down into both windows *g*, *g'*, at once. The two tubes are connected rigidly by the double bridge *m*, and a horizontal rod or stout tube, *n*, joining the bridges, is grasped by an ordinary clamp for fixing the system in place.

If the jets are identical, and communicate through identical lengths of tube with similar tubes *b* (fig. 6) of the steam box *A*, the colors seen by both eyes must necessarily be identical. This state of affairs may be tested once for all. Supposing, therefore, that the right tube, *A′ A′*, is left without interference, the other tube, *A A*, may be manipulated in various ways. Thus one may change the temperature, or the pressure, or the composition of the influx of air or other material at *C;* or the number and size of the holes in the jet may be varied, or the steam variously impregnated with other gases before it escapes at the jet, etc.

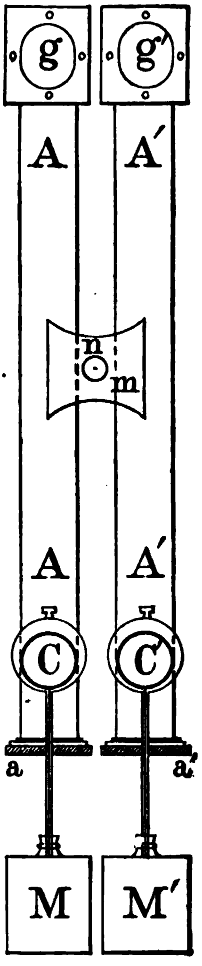

Fig. 11. — Differential color tubes. Front view. Scale $\frac{1}{8}$.

In all such cases the tubes *A A* and *A′ A′* are connected in multiple arc, as it were. But if the jet be removed from *A′ A′*, and the discharge from *A A*, after passing through a suitable length of wide tube, be eventually passed through *A′ A′* without further interference, then these two tubes are connected in series. This adjustment will, I believe, lead to important applications of the present apparatus.

Reviewing the experience of this section it appears that the adjustment of air and steam which secures the clearest field in a color tube must be made as nicely as the adjustment of air and gas in a Bunsen burner. Otherwise the colors are either dull or faint. Doubtless the efflux may at times be stimulated to advantage by an auxiliary ventilating tube containing its own jet, without interfering with the color tube itself. Sections 23, 25. In using the differential apparatus it is convenient to prolong one of the air tubes *C* above the head, but within easy reach, of the observer.

METHODS AND RESULTS.

18. *The succession of colors.*—The first question to be disposed of is the succession of colors. Here I am able to proceed with considerable certainty, seeing that there is a rich harvest of experimental material available. I will arrange these colors in Table 3, stating briefly how they were obtained, and placing the colors where I think they belong. I will also add Quincke's[1] revision of the colors of Newton's rings, when seen normally by transmitted white light, as quoted by Kohlrausch,[2] for comparison.

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[1] Quincke: Pogg. Ann., cxxix, p. 180, 1866.

[2] Kohlrausch: Leitfaden, 5 ed., p. 340.

Table 3.—*Showing the succession of colors.*

[Data of the last column for air, white light, and normal incidence.]

By exhaustion.			Experiments with jets.					Colors of Newton's interferences.	Thickness of plate of air in millimeters.
Kiessling. 1884.		Aitken. 1882.	Helmholtz. 1887.	Aitken. 1892.	Barus. 1892.	Present method.			
					White.	§ 17. Fig. 8 with sulphur. § 25, moist gas jet.		White.	.000,020
		Pale yellow.		Yellow.	Yellow.			Yellow white.	.000,048
								Brown white.	.000,079
					Orange.	§ 9, efflux violent.	Jet of continually decreasing intensity of flow from the top to the bottom of this series of colors.	Yellow brown.	.000,109
	(Second, third, and fourth series.)	Slightly reddish.		Brown.	Brown.			Brown.	.000,117
					Opaque.	§ 17, efflux noisy.		Red.	.000,129
(First series.)	Pale purple.			Opaque.	Opaque.			Carmine.	.000,133
					Opaque.			Dark-red brown	.000,137
Pale lilac. Pale blue violet.					Dark violet.	§ 17, efflux intense.		Dark violet.	.000,140
					Indigo.			Indigo.	.000,153
		Blue.	Blue.	Blue.	Blue.	§§ 17, 14.		Blue.	.000,166
Light blue.	Stone gray.				Gray blue.	§§ 17, 14.		Gray blue.	.000,215
Blue green.					Blue green.	§§ 17, 14.		Blue green.	.000,252
Emerald green.	Olive green.	Green.	Green.	Green.	Green.	§§ 17, 14.		Pale green.	.000,268
Yellow green.	Yellow green.							Yellow green.	.000,275
					Green yellow.	§§ 17, 14.		Yellow green.	.000,282
Green yellow								Green yellow.	.000,287
Light orange	Bronze yellow.	Yellow.	Yellow		Straw yellow.	§ 17, 14.		Yellow.	.000,294
	Orange.							Orange.	.000,332
Dark orange.		Brown.			Muddy brown.	§ 17.		Brown orange.	.000,364
Pale scarlet.								Light carmine.	.000,374
Pale purple.		Purple.	Purple.	Pale crimson. (Uncertain.)	Pale purple.	§ 17.		Purple.	.000,413
					Pale violet purple.	§ 17.		Violet purple.	.000,421
					Pale violet.	§ 17.		Violet.	.000,433
		Blue.	Blue.		Pale indigo.	§ 17.		Indigo.	.000,455
								Dark blue.	.000,474
					Faint green.	§ 17, jet nearly shut off.		Green blue.	.000,499
		Green.						Green.	.000,550
					Faint yellow green.	Long tube, § 25.		Yellow green.	.000,564
		Yellow.			Beyond recognition.			Dull yellow.	.000,575

Kiessling[1] was the first to call attention to the striking similarity of the order of colors at the centre of his field, to certain Newtonian interferences ("gewisse Newton'sche Interferenzfarben"). After him Aitken[2] points out the same fact more at length. The remarks of these gentlemen, however, are cursory and vague. Thus Aitken believes the colors to be interferences by reflection of the second and third order, whereas my results show interferences by transmission of the first and second order, terminating at the third.

Kiessling's results need some explanation. His first series of colors is produced by compressing surcharged, suitably dusted, air, and then allowing it to expand suddenly to atmospheric pressure. The experiment being made in a glass sphere illuminated by sunlight, the colors are observed in the axis of illumination. The succeeding series are obtained by aid of an exhaust pump. They are less easily located relatively to Newton's scale (see end of table) than Kiessling's first series. Indeed, I am at a loss to know, from his description, whether the whole of the four series (the colors gradually become fainter till they fade completely) can be obtained in a single exhaustion, or whether they are the results of successive independent exhaustions. I have inferred that the latter case holds, and have so placed the colors. In any case one would expect them to become gradually more complex and mixed. The first series is intensely brilliant. Diffractions necessarily enter.

Aitken, who exhausts long tubes, gets a wider range of colors running (as I interpret them) from the first into the third order.

Von Helmholtz saw all his colors in the successive regions of an open steam jet, and reasonably inferred that the remote and cooler parts contain the larger particles. Aitken's jets play into tubes, as stated above. Section 11.

With regard to my own work, most of the colors from the browns of the first order to the purples of the second can be produced in the tube, fig. 8, by simply decreasing the pressure under which the steam issues from about 80 cm. of mercury to zero. But all the colors are dull, the initial browns muddy, and the final purples so faint as to be hardly perceptible. However, to obtain the white, yellow, orange brown, and brown red of the first series in a state of great brilliancy, it is sufficient to let the steam jet suck the flame of sulphur into one of the air tubes *f*, fig. 8, the others being closed. In this way particles of sulphur are volatilized, unchanged, in an atmosphere of SO_2 and they reach the jet in a state of extreme comminution. Moreover, the full heat of the flame is sufficient to prevent all condensation (white), in spite of the sulphur nuclei; but by gently withdrawing the flame the cloudy condensation gradually becomes incipient (yellow) and eventually more marked

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[1] Kiessling: "Dämmerungserscheinungen," p. 140, 1884.

[2] Aitken: loc. cit., p. 433: "As no white follows the first blue it seems probable that the first spectrum * * * is not observed; * * * ." But this is the property of the first order of reflected interferences only, as stated in the text.

(brown). Hence these water globules must be of an extreme order of minuteness, their size increasing actually from zero (vapor) to the dimension corresponding to brown. When the flame is withdrawn the field at first becomes opaque, and then runs through the blues and subsequent colors of the schedule—a result also agreeing with the inference stated.

Similar effects, but less striking, may be obtained with a Bunsen burner.

To obtain all the colors (except the initial white and light yellow, perhaps) brilliantly, and with a special view to minute differences of tint, the apparatus figs. 9 or 11 must be used. This is the way in which the table was constructed.

In addition to the data of the table, the pressure in the steam box, which under fixed conditions gives a definite color, might have been added. But this is the purpose of the next chapter.

19. *Possibility of interference.*—If now the two parts of the above table be compared, there can be no doubt that the succession of the colors of cloudy condensation is identical with the corresponding succession in Newton's rings, of the first and second order,[1] seen by transmitted light under normal incidence. Section 20. Thus it is worth inquiring whether this is more than a coincidence, or whether small water globules, all of the same size, color normally transmitted white light, like thin plates.

For a given homogeneous color, if I be the intensity of the incident light and k the reflection coefficient (0.04—0.05 for the given conditions), then, after a single transmission, the interference maxima and minima are $(1-k)^2\,(1+k^2)\,I$ and $(1-k)^2\,(1-k^2)\,I$—that is, they differ only very slightly and the rings are scarcely perceptible. But if there be an indefinite number of particles, all of the same size, available, then this process is indefinitely repeated in such a way that while the light already colored is not extinguished the admixed white light becomes continually more fully colored. Thus, after a sufficient number of transmissions, the emergent ray may show intense color.

Hence, wherever particles are in great abundance, full and deep colors may be looked for; and when particles are not present in great quantity the colors are necessarily pale, dependent as their intensity is on the frequency of transmission. Clearly, when the jet is nearly shut off, the mixture is more dilute then for intense jets, while in both cases the vapors fill the color tube by expansion.

20. *The opaque field.*—Between brown and dark violet in the colors of the first order there is an opaque region. Sometimes the brown takes on a reddish hue and sometimes the violet appears purplish. But the opaque region of indefinable color (section 25), either in long or short color tubes, remains. Indeed, it is a characteristic landmark in the color territory. Being absent in exhaustions, it is clearly to be referred to the jet, and is to be interpreted in accordance with the researches of Osborne Reynolds[1] on the flow of liquids in pipes. Reynolds found that a colored jet passing through clear water remains uniformly filamentary, so long as a certain critical velocity of efflux was not exceeded. After this the jet breaks up suddenly and violently into eddies. In the present experiments this critical velocity coincides for steam with the opaque field of the color tube; or, in other words, at this rate of efflux the stability of the jet breaks down. Here, therefore, one would scarcely expect to find particles of the same size throughout.

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[1] The colors fade at the beginning of the third order.

But this reason is not quite adequate; for, if the intensity of the jet be still further increased, magnificent browns and oranges appear. To account for opacity it is thus essential to inquire into the relation of color to size of particle, at the point where color is extinguished.

In the annexed diagram, fig. 12, I have laid off Newton's colors as abscissæ, by simply platting off equal distances for each step of color.

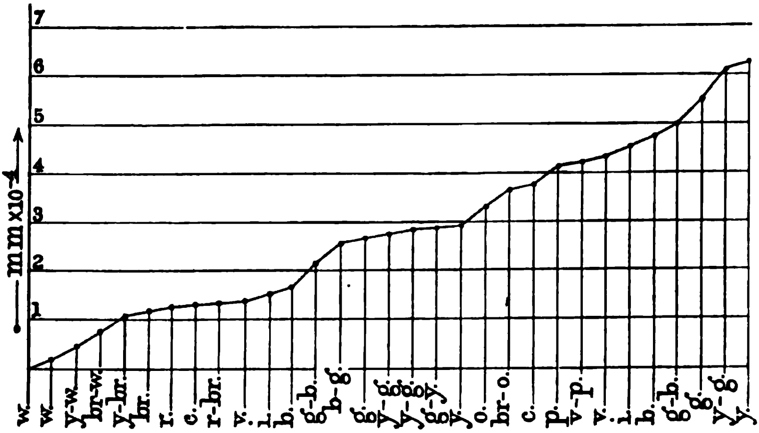

FIG. 12.—Diagram showing the colors of Newton's interferences by normally transmitted white light, as dependent on the thickness of the plate in ten-thousandths of a millimeter.

The ordinates are the corresponding diameters of the particles as given in the above table, and referred to air.[2] Thus it is seen at a glance that whereas, between white and brown and between violet and green, the colors change slowly and uniformly for relatively rapid increments of diameter, quite the converse of this holds good for the intermediate space between brown and violet. These hues would be very sensitive as a criterion for variations of the size of particles. Furthermore, a mixture of these colors is virtually black to the given conditions of transmitted light. Hence, if a stable but rapidly-flowing steam jet topples out of equlibrium just at this region of colors, an opaque field would seem to be inevitable.

A similar explanation may be offered to the straw color of the yellow following the blue greens; but here the insufficiency of ventilation is already a matter of consequence.

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[1] Reynolds: Phil. Trans., London, III, p. 935, 1883; cf. p. 957.

[2] The water particles being smaller than this in the inverse ratios of the indices of refraction. Nothing would be gained by platting cubes of diameters.

21. *Color tube by reflected light.*—If the jet which has been made opaque by dust or otherwise, and which in the free air appears blue (say) by transmitted light, be projected against a dark background, the complementary purple appears distinctly. Similarly in the color tube, if any part of the field be dark, this tends to take on the complementary hue of the field proper. Phenomena such as these are not simple, for they may result from physiological contrast and be merely subjective, or they may be truly physical.

Hence I made a special study by aid of the apparatus fig. 10, where the only light which can reach the eye (after proper screening) is that reflected by the steam corpuscles themselves. Looking into a tube of this kind, when no steam is admitted, the sides and opaque top *a* are faintly seen. Again, when pure steam, either without air or with filtered air, passes, the colorless clearness remains and the presence of steam reveals itself to the eye only by the shifting and dancing of the interior. When, however, dusty air is admitted, the column is at once opaque, of a pale neutral white color, and, so far as I could see, it makes no difference what the color of the transmitted light may be, or how the tube is manipulated.

Now this is precisely what one would expect, since the case is nearly the converse of section 19. For a single particle and homogeneous light, the beams which interfere are $k\ I$ and $k\ I\ (1—k)^2$; i. e., they are weak but nearly equal in intensity, and the interference is very perfect and brilliant. But it is not capable of indefinite repetition, for after each interference the direction of the ray is reversed. Hence such light, if at any depth, is either entrapped in the color tube or it can only emerge from the tube (no matter whether front or rear end be considered) by being transmitted through the particles as in section 19. Light, however, which has already been colored by reflective interference and is now also compelled to interfere by repeated transmission, can only have retained the colors simultaneously present in both complementary colors. Hence it is virtually extinguished, and all one would expect to see is a dull white effect of diffuse light. In the same way light colored by repeated transmission could not survive reflective interference.

Finally, the only case in which colors by reflection are anticipative is the one presented at the beginning of this paragraph—the case where the free mantle of the jet is looked at against a dark background; for inasmuch as the interference by reflection is under like conditions much more intense than interference by transmission, the former, up to a given normal depth, might well prevail over the latter and hence be appreciable.

22. *Size of corpuscles.*—In so far as the views just presented are correct, the size of the prevailing particles is at once given in terms of the colors of the column seen by transmitted light. It is merely necessary to divide the data of Table 3, in section 18, by the refractive index of water (practically to multiply those numbers by three fourths) to obtain the diameters of the particles producing a given color. Thus it appears that if the prevailing diameter be (say) 0.000,004 cm., the first of the visible colors, the yellow of the first order, looms into view. If (at the present stage of completion of my apparatus, section 17) the prevailing diameter be 0.000,040 cm., the last of the visible colors, the faint green at the end of the second order, will appear. Between these extremes something over fifteen different steps of diameter are recognizable.

It is interesting to compare this order of values with the data obtained by v. Helmholtz (loc. cit.). Utilizing the equation due to Lord Kelvin,[1] according to which, at a fixed pressure and temperature, the excess of vapor tension at a convex spherical surface is directly proportional to the surface tension and inversely to the radius of curvature, v. Helmholtz found by direct experiment that diameters between 0.000,015 and 0.000,026 cm. must have been encountered in his work. This is very near the mean of the values found above from interference data. It corresponds to the field between blue of the first order and purple of the second order, and this is the most intense and persistent part of the field.

To recapitulate. If the colors of cloudy condensation seen under normal incidence (in tubes) be regarded as cases of Newton's interferences by transmission, the order of succession, the occurrence of intensity and of faintness of color, the position of opacity, the absence or partial absence of color by reflected light, and the mean size of the active particles is well represented. This does not yet amount to a proof of the proposition as against diffraction;[2] but it is certain that the increase or decrease of the size of particles has been correctly interpreted in terms of color qualitatively at least, if not quantitatively, and that the absolute sizes derived can not be far wrong. Bearing this in mind, the color scale may be safely accepted. I shall probably recur to the matter more rigorously at some other time, and whatever correction be necessary can then easily be applied.

23. *The condensation problem.*—With these views laid down, the remarks of earlier paragraphs (sections 10, 17) may be resumed. In the differential apparatus, fig 11, let the two tubes A and A' be connected in series, as shown in the annexed diagram, fig. 13. Here the jet of A' is removed, and the vapor discharged from A is conveyed by a sufficient length of tubing, D, of the same diameter, into A'.

Then the progress of the condensation—i. e., the difference in the size of water globules in A and A'—is at once given by the difference of color of the two tubes.

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[1] Sir William Thomson: Proc. Roy. Soc. Edin., 1880.

[2] For in both cases the superposed maxima and minima must for any homogeneous color lie at distances apart proportional to the wave length.

The time taken by the vapor in making this passage, or the velocity of the current, can be accurately determined as follows: After a permanent colored field has been established, let the flame of a Bunsen burner be quickly moved across the air hole *C*. The effect of this is to superheat the steam issuing from the jet, and therefore a momentary flash of bright light is seen in *A*, followed at once by an opaque field due to the (cold) dust in the wake of the flame. This flash travels like a clear bubble through the whole length of tubing *D*, and is eventually seen at *A′* quite as brilliantly as at *A*. It is therefore only necessary to note the time between the transit of the Bunsen flame across *C* and the flash in *A′*, in order, with the known length of tubing *D*, to determine the rate of flow.

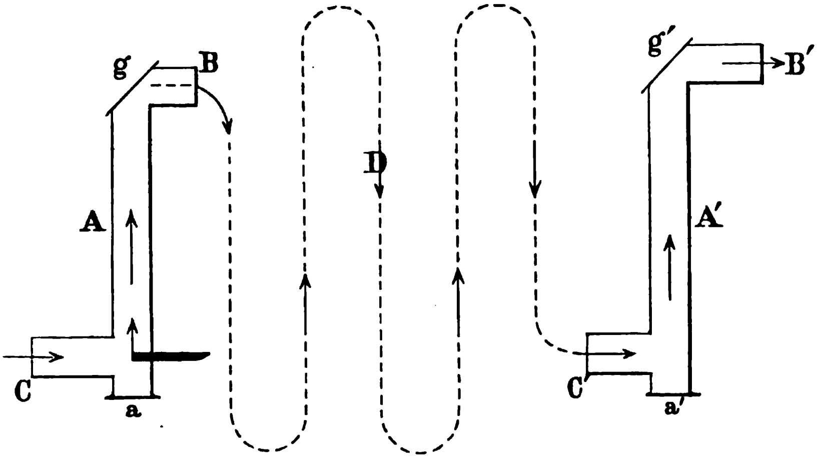

FIG. 13.—Differential color tubes. Arranged in series.

Inasmuch as this is a problem into which I am entering at some length, I will here only cite a random example:

Length of tubing *A D A′* (with allowances for ends), 300 cm

Time between flashes, 1.2 seconds.

Color of *A*. Green, yellow, blue, opaque.

Color of *A′*. Green, yellow, blue, opaque.

In other words, under these conditions there is no perceptible condensation (i. e., enlargement or decrease of the water globules) in six-fifths seconds. It follows from this result that a very considerable length of tubing, *D*, is required in these experiments. One difficulty is to be guarded against—the train *D* introduces an appreciable resistance to flow. Hence the ventilation is apt to fall below the necessary value, whereupon the colors in *A*, and particularly in *A′*, become dull. I think this can be counteracted by attaching an auxiliary vertical tube with an especial ventilating jet at *B′*. In this way the experiment proper is left without interference.

Quite a number of other questions, chiefly in reference to the flow of gases in tubes, and to jets, suggest themselves for solution here, into which I will not enter. Temperatures at any part of the system may be measured, thermoelectrically at least, and within certain limits they may be varied. Concentrated sunlight, for instance, can be made to actually permeate the substance of the current. Again, the discharges of two independent different colored tubes *A* may be mixed in the train *D* and caused to react on each other while the effect is observed in *A′*, etc.

The other two factors which enter prominently into the present work are the amount of adiabatic cooling at the jet (which is, perhaps, open to computation and also to thermoelectric measurement, and which may be varied by connecting the color tubes in multiple arc, as shown in fig. 11, and putting a stopcock in one of the tubes, *b*, fig. 6) and the temperature of the medium into which the jet discharges. To study the latter case (supposing the color tubes connected in multiple arc, fig. 11), *C* is to be joined with a train of tubing supplying air at any temperature and suitably dusted.

Results so obtained, in addition to their meteorologic bearing, have a general physical significance as well. The reasons[1] why an intense or intensely supersaturated jet is (cæt. par.) shattered into smaller fragments than a gentler efflux will be briefly indicated in section 27. The three experimental facts on which I am justified in putting stress are: (1) the occurrence of a marked degree of supersaturation; (2) the color-producing particles are an almost instantaneous growth; (3) after being produced they retain their individuality as to size indefinitely (relatively speaking and proper conditions presupposed). These, I think, will adequately account for the sudden action and the equally sudden and definite cessation of the drop-producing tendency exhibited in the above experiments.

24. *Dust and flames.*—Utilizing the apparatus above, I made a great number of special experiments, into which, however, I can only enter here in a cursory way.

If, when the apparatus, fig. 8, is in action and the field of the usual gray-blue color, any dust be set free in the neighborhood of the air tube *f*, the field at once becomes opaque. What is meant by dust here is not so much the noisome article of household economy, nor smoke necessarily. Dust in the present sense is preferably far more comminuted material (section 27), such, for instance, as arises out of a clear perfect Bunsen flame, or from glowing (not smoking) charcoal (Japanese punk), or from cold phosphorus, or from the sodium tinge in the outer mantel of an alcohol burner, or from a sulphur flame (Kiessling), or from the surface of an almost tensionless liquid like ordinary concentrated sulphuric acid (v. Helmholtz), etc. Take the apparatus (fig. 8) with all the air holes open, and let a small clear Bunsen flame be placed on the table above the level of *f*. No effect is produced on the color of the field; but if the same burner is put on the floor in the free air, much over a meter below f and even laterally from it, the densely opaque field soon appears and persists for some time, even after the burner is again placed above the table. This conveys some notion of the sensitiveness of this apparatus, and the dusty exhalation of the little flame.

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[1] The ingenious and picturesque view of the case taken by Mr. Aitken will be found throughout his paper, but particularly on page 423. Cf. section 11 above.

Indeed, if the air tube C of the apparatus fig. 9 be prolonged as far as the ceiling of the room, it will catch the fountain of dust issuing from a small Bunsen flame on the floor at a distance of 12 feet below the mouth of the tube. The field, all but colorless before (faint blue, second order), becomes densely opaque.

As it seems to me, the underlying cause of this striking activity is not merely the traplike action by which the flame collects atmospheric dust, but rather the additional fact that many of the great chunks of such material (metaphorically speaking) are heated to the point of disintegration and volatilization. Thus a whole cloud of nuclei comes into being where a single one existed before; and thus one might expect the hot flames like burning oxyhydrogen (Coulier) to be more active than cold flames like alcohol, since a scattering of planets into nebulæ is the work to be done. R. v. Helmholtz,[1] who is among the chief students of this particular subject, calls attention to Giese's[2] important discovery of the diffusion of ions out of the flame proper, and their continued activity[3] at some distance from it on all sides. Von Helmholtz regards it not improbable that many of these ions are neutralized in the steam jet, and there, by a kind of molecular percussion, induce cloudy condensation—an exceedingly beautiful hypothesis which he is loth to abandon, although throughout his paper his stronger judgment seems constantly to urge him in the direction of more humble references to atmospheric dust. Von Helmholtz does not make a clear case; but the question is an open one and a decision will be difficult, for the experiments, to be worth anything, must be faultless.

25. *Promiscuous experiments.*—If a compressed gas (oxygen) be admitted into the color tube by a collateral jet, the colored field becomes clearer. Admitted with steam into the steam box, the gas pressure replaces the steam pressure, so that without further increasing the flow of steam the colors can be made to pass from the second to the first order, through brown, orange, yellow, almost to white. Thus, by using very little steam (the jet alone showing greenish of the second order) and increasing the gas pressure, I have chased the colors through "opaque" without losing a transparent field. In this way I sometimes detected a reddish hue on passing from dark violet to brown;

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[1] Von Helmholtz: loc. cit., p. 7, 8.

[2] Giese: Wied. Ann., XVII, pp. 236, 519, 1898.

[3] Recalling the more recent researches of Arrhenius (Wied. Ann., XLII, p. 18, 1891), that a sodium flame is a better electrolytric conductor in virtue of the solution of sodium, there is some doubt in my mind as to the sufficiency of Giese's result for V. Helmholtz's purposes.

but as a rule the transition is smoky and peculiarly indefinable. The chief experimental advantage of this arrangement is the occurrence of a jet of a decidedly lower temperature than the pure steam jet. The quantitative value of such a comparison is obvious. If a jet with but one hole, 0.15 cm. in diameter, be compared with a jet containing a number of holes of the same size (differential apparatus, other things equal), and if pressure is continually increased, the latter will reach the opaque field sooner than the single-holed jet. After this the action is reversed, so that the single jet reaches the initial orange sooner than the other, if the other passes beyond opaque at all. When there are more holes than one, the faint colors of the second order are more obvious (as might be supposed), and a peculiar feature is the persistence of intense emerald greens. If the jet contains as many as five holes, the colors become dull. The same dullness is observed for a single jet when the air hole *C* fig. 14, is partially stopped up. (Cf. sections 14, 15.) These experiments have an important bearing on the theory of the condensation process.

Corresponding experiments were made with long tubes, using a single jet. Thus I found, by decreasing the length gradually from 220 cm. to 150 cm., that for all jet intensities the field remains opaque. On further decreasing the length the colors gradually appear, but even at 110 cm. they are dull. Tubes of this kind are serviceable for bringing out the green and green yellow near the beginning of the third order of colors. Section 18.

The temperature of the walls of the color tube does not seem to produce a marked result. Thus I put a wide helix of lead pipe, through which cold water was flowing, into the color tube, fig. 8, but obtained no noteworthy effect beyond a certain loss by condensation. The differential apparatus was not tested in this way.

Fumes of naphthalene, camphor, alcohol, ether, turpentine, etc., when pure, showed no dustlike action. A space filled with naphthalene fumes is rather cleansed of active dust, and I suspect that this action is connected with the formation of little crystals. For purposes like the present, therefore, air in which naphthalene fumes have condensed may possibly be used for filtered air with advantage.

Sulphur chloride (which is decomposed by water liberating sulphur) acts as actively as sulphuric acid.

The action of sulphur itself is more interesting. The effect of the flame has already been described in section 18. Let the flame be extinguished and the sulphur cooled down to the point of incipient freezing—i. e., until the appearance of the surface changes from glossy brown to opaque yellow. On bringing this sample near the air hole *C* of the differential apparatus, the field at once clouds over, even if the influx pipe is above 2 meters long. As the sulphur solidifies further, the series of colors is slowly run through. This experiment might serve to illustrate the difference of vapor tension at the solid and liquid surfaces of the same substance, at the same temperature (Ramsay and Young, Fischer). Furthermore, a stick of sulphur softened in a burner suggests itself as a convenient method of showing the succession of colors described in the above table.

As compared with moist air, dry air must be the better dust carrier, for the particles are not clogged with moisture. The surmise is reasonable, moreover, that a dried particle may be peculiarly effective. Experiments made with air passed over chloride of calcium and phosphorus pentoxide negatived this. These bodies are neutral. Hence, in the case of sulphuric acid, it is actually the vapor which is the active principle, unless, indeed, an air ammonic sulphate be produced.

By far the best dust producer which I have found is a freshly-cut surface of phosphorus at ordinary temperatures; and its activity persists for a long time (certainly many hours) after cutting. The fingers rubbed with such phosphorus are also active. If air aspirated over a piece of phosphorus as big as a pea be mixed with different quantities of room air (coalescence of the conveyance tubes), persistent colors correspond to each degree of mixture, and they may thus be produced at the minimum (all but vanishing) steam pressure. The active agent here is the invisible dust of oxidation; for ozone, according to Mascart, is inactive.

It is important to notice that the yellows of the first order are not affected by dust—another argument in favor of their origin from exceptionally small water globules.

To the effect of the temperature of the air into which the steam is discharged, I shall devote the next chapter. Suffice it here to say that below 9° C. the field is opaque at all pressures. As temperature increases, the steam pressure at which the blue of the first order passes into opaque increases from zero rapidly to a maximum; whereas the pressure at which the yellows of the first order pass into opaque decreases from an enormous value, at even a more rapid numerical rate than before, to a minimum, in such a way that, for normally dusty air, the said maximum and minimum coincide at about 40 cm. of mercury (pressure) and 35° C. Here, therefore, the blue passes into the yellow without an opaque demarcation. Beyond this (air temperature increasing) the colors, which have gradually grown fainter, vanish. The tube is clear and colorless, showing that the supersaturation at the jet is nil.

26. *Electric excitation.*—Von Helmholtz, in his paper on the electrification of jets, leaves the question as to the cause of the phenomenon open, indicating that either the solid matter thrown off from the highly charged point or the diffused ions may be the active agent. His attitude as regards these two hypotheses (both of which he examines elaborately) has virtually been given in section 24, *mutatis mutandis.*

Mr. Aitken throws himself vigorously into his own modification of Bidwell's hypothesis, as already stated in section 11. Aitken supposes that the comminution of drops, necessary to produce an opaque jet, is here maintained in virtue of their electric charges, since the repulsions thus set in action prevent a coalescence of drops. It is noteworthy that no effect is produced unless the exciting electric charge escapes from a point, so that high potential is essential.

Now, I was somewhat surprised to find an observer of Mr. Aitken's acuteness entirely ignoring the misgivings of his predecessor, and particularly so since the recent experiments of Crookes on electric evaporation might well have emphasized the need of such precautions as v. Helmholtz took. For if there be any solid matter escaping from an electric point, the whole argument in favor of a truly electric condensation in steam jets is vitiated.

I made this test experiment: In the apparatus, fig. 8, the jet *j* is in the inside of a practically closed conductor. Hence it will not be acted on by an electric field on the outside of the apparatus. To give further assurance that this was the case, the (only) open air tube *f* was prolonged even 2 meters or more. I then caused the spark of a Ruhmkorff coil to pass across a gap made by two copper needles lying in the same line, with their sharp ends about a centimeter apart. Whenever this arrangement was brought near the open end of *f* (supposing the apparatus in action) the blue-gray field became opaque. Something, therefore, passed between the points of the spark gap, whether metallic dust or other material, which was simply sucked into *f* by the draft, and which affected the jet precisely as a bit of glowing punk would have done. I then adjusted the inductor so that sparks passed at the coil only, and none were visible at the portable spark gap. On again bringing the latter near the open end of *f*, the darkening of the field was evident enough, though not so intense as in the previous case. Even a silent discharge is therefore active.

The same results were obtained with a clean platinum spark gap.

This experiment may be made more beautifully with the differential apparatus, fig. 11. Connect the air hole *C* of the color tube *A A* with an equally wide tube running vertically upward about 2 meters or more away from the jet. Then fix the spark gap in front of the open (upper) end of this auxiliary tube. The key of the induction coil may be held in the hand. Let the initial field of both *A A* and A^1 A^1 be faint violet (say) of the second order. Then, as long as sparks pass across the gap, the field of *A A* turns deep blue or opaque; or, in general, changes in color in the direction from the second to the first order, as the spark gap widens. Indeed, it is possible to obtain almost any of the colors with very little steam, quite permanently in this way, by simply regulating the spark lengths. The field of A^1 A^1 does not change in color. Silent discharges, (i. e., mere alternate chargings without sparks) act definitely but with less intensity.

Hence I conclude that the electrification of a jet by means of a point is at most a complex phenomenon. Although the effect of an electrical field on water jets is beyond question, no unassailable experiment has yet been made to exhibit the occurrence of a similar truly electric effect

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in the case of the cloudy condensation in steam jets. And since only that part of the efflux which lies near the nozzle is influenced, the clear case in favor of the promotion of cloudy condensation by electrification as such is yet to be made. My own belief is that the evidence[1] will not be forthcoming, for reasons set forth in section 27.

I may note, in passing, that in the present experiments (spark lengths increased) augmentation of the number of dust particles produces the same result as did the increased supersaturation in the earlier work. A similar test may be made by holding the mouth of a sulphuric-acid bottle (or hot sulphur, etc.) near the open end of the air tube *C* and then gradually withdrawing the bottle. The field will be found to run through the gamut of colors from opaque to the second order. I accentuate these observations because of their theoretical importance (section 27), remembering that the field at the outset (before adding dust) was pale violet or indigo of the second order and the jet nearly shut off. Thus with little supersaturation the appearance of intense colors and smaller particles is somewhat startling. In no case have I in this way been able to produce the yellows and browns of the first order beyond the opaque, except by using phosphorus or the flame of sulphur. Here, however, heat enters as a factor.

One would expect the particles of the steam jet to be electrically charged, for the reasons given in Faraday's classical researches. I thought it worth while to test the case for a metallic jet, however, as follows: The brass nozzle was electrically connected with the earth and the charge of the jet collected by allowing it to play against an insulated metallic brush communicating with a Mascart electrometer. Producing a blue-gray field in one tube of the differential apparatus, I found that a maximum voltage of +10 was easily collected at the free jet of the other. This maximum increases and decreases markedly with the intensity of the jet. The positive charge is also decreased whenever a drop squirts from the nozzle. No difference between the maximum voltage of an opaque (sulphur) and an ordinary jet (cæt. par.) could be detected; but I do not consider my experiments final.

27. *Conclusion.*[2]—In the above pages I have endeavored to show that a solution of the condensation problem may be regarded as hopeful for a certain class of water globules ranging in size from somewhat less than the sodium wave length of light to about one-tenth of this magnitude; in other words, the growth of the globule, from the latter to the former of these dimensions, can be controlled and studied. For particles smaller and particles larger than the limits given, the method (at its present stage of development) fails. Very frequently, however, laws carefully scrutinized within a given range suggest the behavior within the next range (as I will presently show), or else the method of the one case leads to modifications of method for the other. If 0.000,030 cm. be taken as the limit of microscopic separation, then particles whose size is just exceeding the limit of interference measurement (0.000,040 cm. being the green of the second order and the above apparatus) are just becoming microscopically measurable. The problem thus begins to deal with something decidedly more tangible.

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[1] See reference to E. Kaiser in section 11.

[2] Reference to Hertz, Von Bezold, and other allied researches (see Professor Abbe's collection in Smithsonian Mis. Col., Washington, 1891), will be duly made in my future work. The present paragraph is a mere outline.

In conclusion, I have to advert more definitely to the point of view taken in Chapter I, trusting that the intervening paragraphs have shown the need of a more detailed knowledge of the true isothermals for the change of state-gas liquid. By the term true isothermals, I wish to indicate that the behavior of a free fluid is meant—i. e., one in which there is neither nuclear nor surface condensation, or virtually a dust-free fluid in a vessel ot extensible and absolutely neutral walls. No such vessel exists; hence all the experiments must be of an instantaneous kind, so that the results may be noted before the vessel has time to distort them.

Necessarily the isothermals[1] for this ideal case must be of fundamental importance. Their chief feature may be already inferred. Near the region of changes of state all are characterized by a pronounced volume lag, in virtue of which at a given temperature it takes a higher pressure to change the pure dry vapor back to the liquid state than the pressure at which the liquid just wholly vaporized.

To take a concrete example, let the volume of a given mass of water at 100° C. be allowed to expand isothermally until the whole bulk is quite converted into dry steam. The pressure so obtained is the vapor tension of water at 100°—i. e., 1 atmosphere. Then if the vapor be dust free and contained in the ideal vessel, no condensation can take place on again decreasing the volume isothermally, at 100, until the pressure has reached a remarkably high value. For by hypothesis the only nuclei present must be a collection of water-vapor molecules and must therefore be of molecular dimensions. Hence the condensation pressure must reach the vapor tension at 100° C., at an extremely convex surface. It is interesting to estimate in a rough way about how large this pressure will be. The distance between the centers of two adjacent water molecules is probably greater than 0.000,000,01 cm., and probably less than 0.000,000,1 cm. At 100° the density of dry steam is (say) 0.0006 and of water 0.96. Finally, the surface tension of water in contact with air is at 20°, 80 dynes per linear centimeter. At 100° and in contact with steam the surface tension will be considerably less than this, but the datum given may be temporarily admitted. Hence the excess of vapor tension at a convex (molecular) surface of the diameter 0.000,000,01 cm. is 20 atmospheres, and the corresponding excess at a convex (molecular) surface of the diameter 0.000,000,1 cm. is 2 atmospheres. One should, therefore, be prepared to exert about 10 atmospheres, in order to condense[1] pure dust-free dry steam at 100° C. in an ideal vessel of the kind in question. When the necessary pressure has been brought to bear, the steam would collapse as a whole, supposing, of course, that temperature never exceeds 100° C.

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[1] It is customary to represent the volume of a given mass of fluid as depending on pressure and on temperature conjointly, and convenient for the time being to consider either temperature constant (isothermals) or else to consider pressure constant (isopiestics).

If, instead of pure steam, a mixture of dust-free air and dry steam be given, the phenomenon, in its general features, would retain the character just sketched; for here also there is an absence of other than molecular nuclei. In one respect, however, a difference is manifest—when the condensation pressure is exceeded, the steam would not condense out of air, as a whole, for the case is now virtually one of solution. In other words, the interaction of air and steam is brought into play and successively increasing pressures correspond to successive states of chemical equilibrium. (Cf. Chapter I for the analogous case of liquid solutions.)

This condition of things changes enormously when dust is introduced either into pure steam or into the air mixture. If the diameters of the dusty particles were only one hundred times as large as the smaller estimate of molecular diameter (10^{-8}cm.)—i. e., if the dust particles were only one-millionth of a centimeter thick—they would already reduce the condensation pressure to about 15 cm. of mercury. Dust particles, 1,000 molecular diameters in thickness, would reduce it to about 1 or 2 centimeters.[2] Moreover, the smaller of these particles (taking their density at about 2) would fall through air at the rate of less than 0.000,0006 cm. per second, and would be an integrant part of the air. Indeed, even the larger dust particles (0.000,010 cm. thick), falling at the rate of 0.000,06 cm. per second, could scarcely be separated except by filtration. The marked activity of very fine dust (section 24) is thus accounted for, and the term "dust-free" air is to be used with caution.

Instead of keeping temperature constant and studying volume in its dependence on pressure, the latter variable may be kept constant, and volume considered in its dependence on temperature.

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[1] I think the above experiment actually feasible, not isothermally, of course, but adiabatically. If it is performed it must lead to a superior limit of the absolute size of the molecule, either of liquid water or of any other liquid similary treated. From this point of view such a research seems to me to be of unusual interest, and it may well be included as a part of my problem.

Again, in the case of freezing, the volume lag can actually be measured, as I showed in the Am. Jour. of Sci., XLII, p. 125, 1891. In terms of Van't Hoff's analogy, volume lag expressed in atmospheres would be the increase of osmotic pressure at a convex molecular surface. Hence a reason is given by Thomson's equation for the undercooling of liquids, and the absolute molecular dimension of a solid molecule is defined in terms of known variables and the surface tension of the solid, a quantity which has already been recognized in Auerbach's researches on hardness (Wied. Ann, XLIII, p. 61, 1891, Cf. p. 94). Thus a scheme for the absolute measurement of solid and liquid molecular dimensions is suggested.

[2] These numbers would be smaller if the temperature correction for surface tension were applied. These pressure differences or their equivalent temperatures are to be expected in steam jets.

The inferences are necessarily identical, remembering that an increase of pressure corresponds in its effects on volume to a decrease of temperature. Practically, the methods are more complicated. The only way of producing the condensation in question is some form of adiabatic cooling, so that pressure and temperature are varied simultaneously. But the effects may nevertheless be treated with reference to the elementary cases specified.

It is now in place to endeavor to apply these preliminaries to the actual case of the steam jet. I have worked this out at length, but, without more detailed experiments, I am loth to communicate it. A brief mention of the method pursued will here suffice. It consists essentially in a comparison of the vapor tension at the convex surface of the globule of water and that of the supersaturated steam immediately surrounding it.

If while the particle is growing there were no change of its temperature, nor the pressure of the surrounding medium, then the vapor tension at the convex surface would continually decrease as the size increases. Actually, however, the particle is being heated by the condensation of the water which promotes its growth. The case is therefore not excluded, that a particle increasing in size will show increasing vapor tension at its convex surface, more markedly so in proportion as the number of active dust particles per unit of volume is greater. But this is rather beyond the limits set for the present considerations. It is necessary, however, that at the outset the tension at the surface of the globule be virtually less than the tension of the supersaturated medium, supposing the phenomenon to be looked at by the above isothermal method.

Now the full growth of the particle is attained in an incredibly short space of time, probably in very much less than the hundredth of a second; whereas, when fully grown, it persists under the given conditions, without change of size, for an incredibly long time, certainly many seconds. Section 23. Hence the medium around the particle, losing volume in virtue of condensation, expands adiabatically.

Thus I derive two descriptive equations or curves, one expressing the tension at the surface of the particle in terms of its size, and the other the tension of the immediate neighborhood referred to the same size. If these curves did not intersect the particle would continue to grow forever. But if they do intersect, then there is a point at which the initially smaller vapor tension at the surface of the particle is equal to that of the immediate medium, and beyond which (size increasing) the vapor tension at the surface would exceed that of the medium. This point, therefore, fixes the dimension of the particle stable under the conditions for which the curves were drawn.

These principles contain an easy working hypothesis for the construction of a homogeneous theory of the above condensation phenomena. It therefore scarcely seems worth while to offer further comments until the whole question has been subjected quantitatively to a minute investigation.

CHAPTER III.

COLORED CLOUDY CONDENSATION AS DEPENDING ON AIR TEMPERATURE AND DUST CONTENTS, WITH A VIEW TO DUST COUNTING.

28. *Introductory.*—Mr. John Aitken, who has pioneered the meteorology of dust to a point of formidable importance, describes two distinct forms of apparatus for the quantitative measurement of the dust contents of atmospheric air. The first of these is his well-known "dust counter."[1] It has been widely used, both by himself and others, and needs no comment here. Its trustworthiness seems assured, both in view of the elementary principles on which it is directly based and of the consistency of the results obtained. In one respect this dust counter is unique, for it probably takes account of all the particles, large or small, present in the given volume of air. At least it does not overlook the larger particles. In indirect dust counters (Mr. Aitken's "koniscope" and the apparatus of the present paper being referred to) only a certain range of dimensions of water globules is visible, and it does not follow that all the dust present is contained in the optically active corpuscles. The restricted use of koniscopes is not necessarily a disadvantage; for the particles counted may be the very ones of interest. Indeed the whole question resolves itself into the character of the problem to be answered.

At the outset, therefore, it does not seem obvious that the indications of the two classes of instruments need necessarily be identical, and a calibration of one in terms of the other is to be made cautiously, so long as certain grades of dust are optically less active than others.

In the "koniscope" Mr. Aitken[2] has endeavored to express the dust contents of a given sample of air in terms of the color, or of the intensity of color, or of the amount of exhaustion necessary to produce a given color, when the cloudy condensation is produced by sudden expansion of the gas in a suitable tube, containing enough moisture to saturate the air. The importance of temperature is pointed out, but not evaluated. Mr. Aitken prefers to make the estimation in terms of the color intensity of the blue, and the apparatus is graduated by comparing it with the direct dust counter. Based as this apparatus is on color discriminations, it is not adapted to give more than a few steps of dustiness, and Mr. Aitken chiefly recommends it for qualitative purposes—such, for instance, as may present themselves in sanitary work.

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[1] Aitken: Trans. Roy. Soc. Edin., xxxv, part 1, 1888; ibid., xxxvii, part 1, No. 3, 1892; Proc. Roy. Soc. Edin., xvi, p. 135, 1889 (containing full descriptions); ibid., xviii, p. 259, 1890–91; Nature: xxxvii, p. 428, 1888; ibid., xli, p. 394, 1890; ibid., xliv, p. 279, 1891; ibid., xlv, p. 299, 1892, and elsewhere.

[2] Aitken: Proc. Roy. Soc. Edin., li, p. 425, et seq., 1892.

29. *The present method.*—During the course of my experiments on the thermal distribution in steam jets, I had frequent occasion to note the actuating steam pressure at which the intense blue-violet field of my color tube merges into opaque, eventually to reappear (pressure increasing) as an orange-brown field of the first order. It struck me that here was a sufficiently sharp criterion for fixing a value of pressure depending in the given apparatus only on the temperature and the dust contents of the inflowing air. In other words, for a given kind of air and at a given temperature, there are two well-defined pressures at which color (blue and yellow) vanishes into blackness. If the kind of air remains the same while its temperature varies, the paired values of pressure will also vary markedly, so that the margins of the opaque field may be mapped out in a diagram in which pressure is expressed in its dependence on temperature. It is the chief purpose of the present paper to show the character of this diagram, and to indicate the manner in which the positions of the loci vary when the dust contents of the inflowing air are also varied. Incidentally I will endeavor to ascertain the more immediate cause of the opaque field, and to see whether the water molecules may not themselves become nuclei of condensation. Section 42.

30. *Color apparatus.*—A full account of the necessary apparatus is given in fig. 14, where the color tube is shown at *A A*, and the method of varying the temperature and dustiness of the inflowing air is shown at *E*, *D*, *F*. The color tube is identical in form with the apparatus described in Chapter II, section 15.[1] I need only to call to mind here that the steam issues at the jet *j*, from a nozzle about 0.16 cm. (one-sixteenth of an inch) in diameter, and that the tube *A A* is about 50 to 60 cm. long, and, in common with the air hole *C*, about 5 cm. (2 inches) in diameter. The glass plates *g* and *a* are kept clear by moistening with a solution of caustic potash, and the mirror *M* reflects sky light through the tube. Mixed steam and air escape at *B*, and provision is made (not shown) for screening off extraneous light from *g*, the window through which the color observations are made.

The two essential appurtenances are the thermometer *t*, to register the temperature of the inflowing air at *C*, and the open mercury manometer (not shown), by which the pressure of the steam entering the jet *j* is measured. Inasmuch as a mercury thermometer is not very quick in its indications, the air at a given temperature must be allowed to pass over the bulb of *t* for some time before the record is taken.

The steam used was generated in a copper globe about 25 cm. in diameter and provided with a water gauge and a steam gauge. The vessel is heated by a large ring burner[1] and is strong enough to withstand, say, 10 atmospheres, though in the present work pressures below 2 atmospheres fully suffice.

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[1] Barus: Am. Meteo. Jour., IX, p. 488, 1893.

G and *H* are forms of air filters, to be described in section 41.

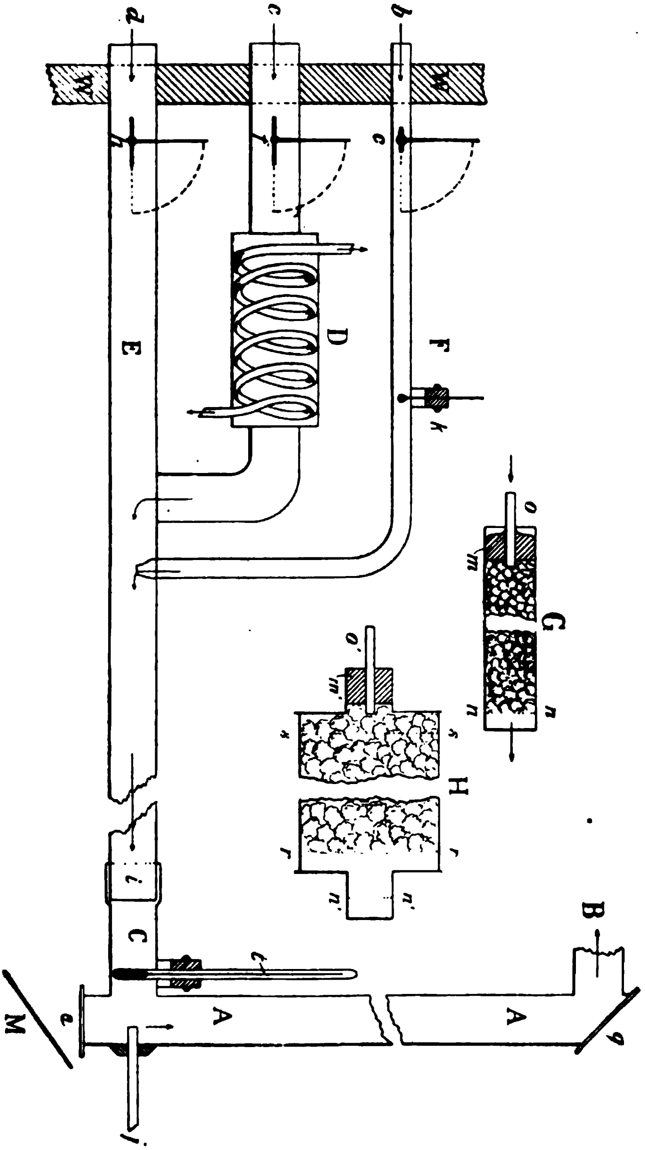

Fig. 14.—Color tube *A A*, with attached heater *E D*, duster *F*, and other appurtenances. *G* and *H* filters. Sectional elevation. Diagram.

31. ***Influx tubes.***—The air entering *C* is taken out of the atmosphere, the three influx tubes *E*, *D*, *F* passing through the window frame

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[1] This apparatus used for other purposes is shown in Bulletin United States Geological Survey, No. 54, p. 60, 1889.

W W and opening into the air on the outside, as shown at *b*, *c*, *d*. Valves are inserted into each of these tubes at *e*, *f*, *h*, so that the quantity of air passing through any one of them may be regulated or even quite shut off. In the winter, when the valves are open, the air rushes through the tubes with considerable velocity, even when the jet *j* is not in action. This velocity increases with the steam pressure actuating the jet, but can be regulated by shutting off the valves *e*, *f*, *h* partially.

The tube *E* is clear, and the air passing through it has the temperature of the atmosphere. The tube *D* discharges into *E* and is provided with a drum, containing a coil of thin lead pipe of about 0.6 cm. (one-fourth inch) caliber. About twenty turns of pipe, each somewhat less than 5 cm. in diameter, in a drum 35 cm. long and somewhat less than 10 cm. in diameter, are more than sufficient. In the winter time steam is passed through the lead pipe. Hence by suitably regulating the valves *h* and *f*, the air flowing through *C* may be kept at any desirable temperature; and, as temperatures between 9° and 40° only are needed for the present purposes, this arrangement is quite satisfactory. In the summer time chilled brine or an expanding gas circulating through the coil will probably be serviceable.

The tube *F* also discharges into *E*, and is useful for increasing the dust contents of the air entering *C*. For this purpose a little closed basket of wire gauze attached to a wire passing through a perforated cork, is inserted into the aperture *k*, as shown in the figure. A piece of phosphorus is put into the basket. The dusty exhalation of a freshly cut surface of phosphorus is almost nil at 0° C., but increases with great rapidity when the temperature rises. Section 11. At any given temperature above 15° its dust supply is nearly constant for a long period of time (hours); hence its availability in the present work, unless the weather is very cold. Fortunately cold temperatures can usually be dispensed with when artificially dusty air is examined.

It is to be noted that all the tubes *E*, *D*, *F* must pass out of the room. If, for instance, *b* opened into the room (which would often be desirable, for the reasons just mentioned), then, if the jet is not in action or only slightly in action, cold air would pass into *C* and *D* and out at *b* as well as at *B* into the room. At low steam pressure the flow of dusty air would, therefore, necessarily be irregular. An advantage is secured by making the common tube *i C* long, so that the air may be well mixed before impinging upon the jet. At best, however, air dusted in this way is an inferior substitute for atmospheric air, and the results show much more fluctuation. Each of the valves, *h*, *f*, *e* is provided with a suitable dial and an index. The valve *e* must be free from leaks. It is best, moreover, when atmospheric air is examined, to remove the basket *k* altogether, and to close the hole with a cork. The hole through which *F* discharges into *E* need not be more than 0.5 cm. (one-fourth inch, say) in diameter, and it is advisable to carry it into the axis of *E* by aid of a glass tube. The whole train of tubes is easily made of ordinary tinned drain pipe and suitable elbows. To summarize, the faint phosphorescent glow visible on phosphorus in the dark is a nearly permanent dust producer. This phosphorus-tainted air, discharged through a one-fourth inch to one-eighth inch tube into the 2-inch tube of pure air, usually produces persistent color effects at ordinary temperatures. Thus the dilution is less than one one-hundredth.

32. *Errors.*—A few remarks on the shortcomings of the apparatus may be made here. It is clear, in the first place, that the temperature of the air entering *C* will vary with the intensity of the jet—i. e., the velocity of current—even if the other adjustments remain unaltered; for the more rapidly the air passes through the drum *D* the less it is heated. This, however, is no serious inconvenience since temperature is measured at *t*.

Similarly the amount of dust introduced into the air will (probably) depend on the rate at which the current passes the basket at *k*. Hence at great jet intensities the air will be less dusty than for small intensities. I have found no easy way by which this discrepancy can be evaluated, and my experiments with artificially dusted air are intended rather to show the character of the dust variation than to map out precise loci. Sections 38–40. Fortunately the dust effect is so striking that there is no possibility of misinterpretation. Experiments which I made by introducing dust with jet pumps and aspirators showed no advantages. To vary the dust contents uniformly at all jet pressures the mouths *c*, *d* of the air tubes must be introduced into a large artificially dusted room, instead of the atmosphere. But this method also presents grave difficulties. The final resort seems to be to examine the atmosphere at different times and in different places, or to construct apparatus for the rapid filtration of air. Sections 41, 42.

One serious theoretical question may be referred to here. It is necessary that at all steam pressures the amount of air entering *C* should be nearly proportioned to the amount of issuing steam. No doubt this is nearly the case; for not only do the air and steam currents increase and decrease together, but the air is admitted in excess of the quantity necessary to produce condensation at the supersaturated parts of the jet, and it is to this condensation that the color indications apply. If the valve *e* be closed and the valves *f* and *h* all but closed, the pressures at which the margin of the opaque zone appears from blue increases; but the temperature registered at *t* also increases at even a greater relative rate, so that the apparent effect is curiously enough rather an excess than a deficiency of dust. Section 40.

I infer from this that in the work below the air is always admitted in quantity sufficient to produce its maximum dust effect. To test this question preliminarily, I replaced the 0.16 cm. nozzle by another 0.09 cm. in diameter, and thus (cæt. par.) only discharging one-third as much steam as the former. The new results virtually coincided with the old (section 42); and hence, though the relations below were obtained from a given apparatus, they are probably true generally[1] so long as the inflowing air exceeds a certain minimum quantity. A full discussion of all these points will be in order after the laws relating to steam pressure, air temperature, and color have been fully exhibited. I will then show (sections 44–45) to what extent each jet possesses special hydraulic properties, depending on the degree of smoothness of bore.

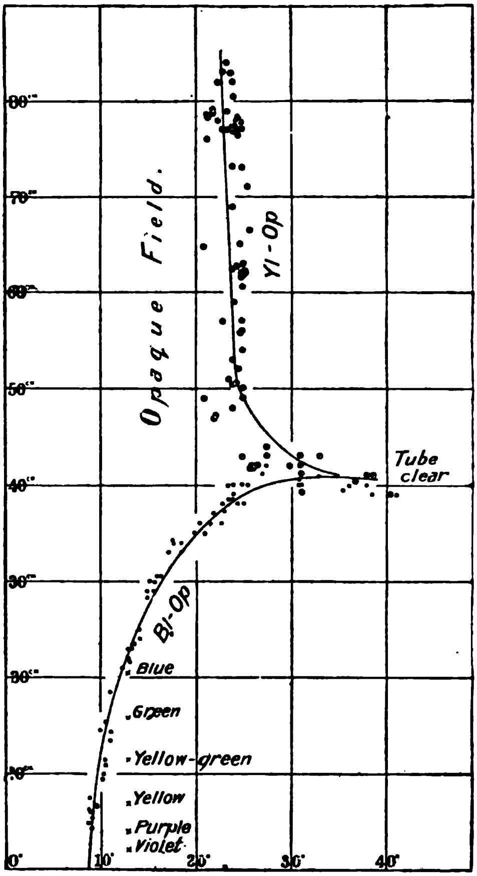

FIG. 15.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

The fact that pin-hole jets are quite sufficient makes the practical construction of the apparatus, fig. 14, on a small scale an easy possibility. A globular copper boiler 5 inches in diameter, and a sensitive steam gauge with a capacity of less than 15 pounds, are available for generating the steam and recording pressure.

33. *Results. Normal atmosphere.* — The results in hand are necessarily in very great number, for the case is one in which the observer has to construct the mean value or path, when the observations themselves are unavoidably discrepant. It will, therefore, be expedient to avoid cumbersome tables, by expressing all the data graphically. An ulterior advantage is gained in this way, inasmuch as the broad features of the phenomena are at once evident to the eye.

In the chart, fig. 15 (and in all succeeding charts), the abscissas indicate the temperature, in degrees C., of the air entering the color tube at *C* (fig. 14); or, in other words, the registry of the thermometer *t*. The ordinates show the pressures in cm. of mercury under which the steam is forced out of the jet. The points of the curve between 0 and about 40 cm. then show the corresponding values of air temperature and steam pressure, at which the blue-violet (first order) field seen in the color tube merges into opaque. The points of the curve lying quite above 40 cm. show the conditions at which the brown yellows of the first order just emerge from the opaque. Curves indicating the approximate loci are drawn through the points.

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[1] It will be expedient to consider the small differential effect of variations of the barometer, and the tendency of the pressure (blue opaque) to fall with the time of efflux, elsewhere.

Below about 9° C., therefore, the field is opaque at all pressures. Above 9°, the pressure at which blue changes into opaque rapidly increases with increasing temperature; and the pressure at which brown yellow changes to opaque decreases from an enormous value, and at even a more rapid rate, as temperature increases. Both loci, curving at a gradually retarded rate, eventually reach a common asymptote at about 41 cm. (temperature being indefinitely high). At the same time the colors which were very intense at the lower temperature gradually become fainter and the opaque zone more translucent, until, at about 40° of air temperature (depending on the size of the nozzle, section 42), the field is clear and without color. The escaping steam is gaseous and not visibly condensed. When temperature decreases again from 40°, white yellow is the first color to appear, showing that the particles here must be the smallest of the whole series. At 35° the change from faint yellowish tones to faint white blues, when pressure is made to vary suitably (see chart) from larger to smaller values, is quite marked. There is no opaque demarcation, however, but rather a mixture of colors, for the opaque field is hardly impervious to light above 30°. Indeed, one often notices a brownish field surrounding the jet, on a violet-bluish ground.

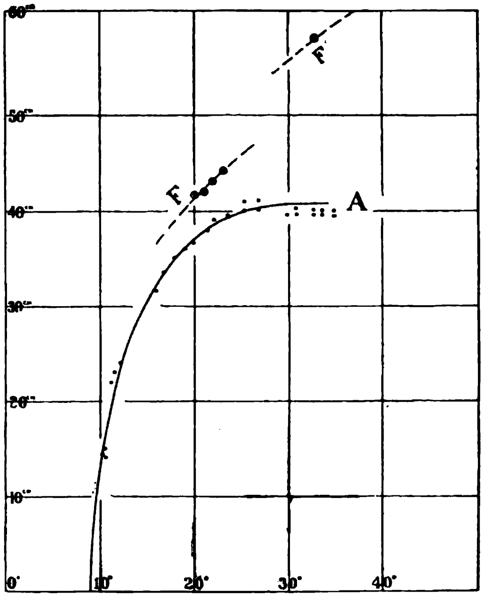

FIG. 16.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

For all temperatures and pressures lying to the left of the two curves the field is opaque, and it sends off a kind of cusp to penetrate into higher temperatures. There is a characteristic difference between the contours of the two margins; for, whereas yellow-opaque after a sharp inflection shoots up almost vertically, blue-opaque shows a regular change of curvature throughout.

At about 13° in the chart, I have inscribed the approximate positions of the successive interference colors,[1] indicating their positions by a cross. This can not be nearly so well done as the location of the opaque margin, and, as the colors are of smaller interest in the present chapter, I will not enter into the subject further. The contour of the successive color curves is easily surmised from the line for blue opaque. Similarly above the yellow opaque line, a family of browns, oranges, and yellows may be located.

When the dust contents are increased, the margin of the opaque field approaches the abscissa, and hence the color loci will be successively more crowded together.

In the chart, fig. 15, only a single air tube (*D*, fig. 14) was available. The air was heated to about 40° by the circulating steam. This was then shut off and the temperature and pressure at which the colors disappeared noted on cooling. The mercury thermometer is scarcely sensitive enough for such observations, and the temperatures of the diagram are probably too high. I have, therefore, lumped all my observations between February 10 and 23, 1893, in this chart, seeing that the phenomenon as a whole is well represented.

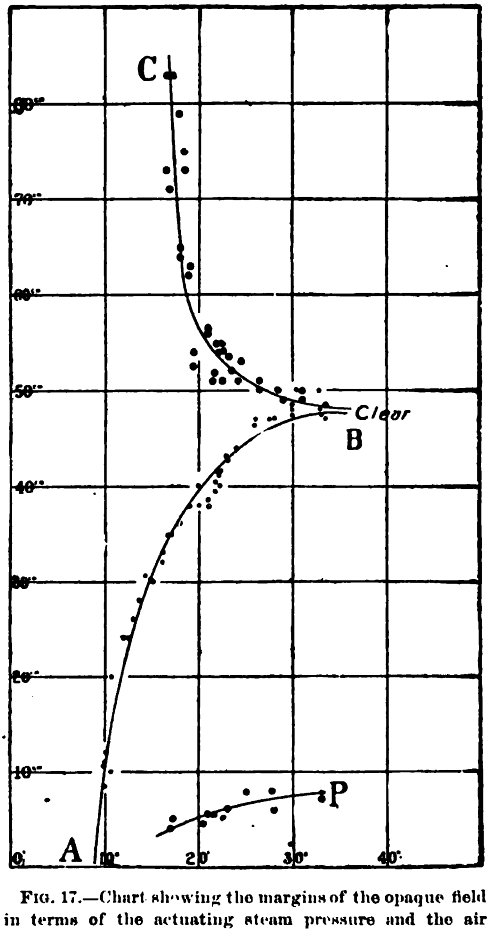

FIG. 17.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

34. *Further data.*—In the following work, however, the apparatus, fig. 14, was used, with the phosphorus tube closed up and the phosphorus removed. Great care was taken to wait for stationary temperatures, and about five (or more) steps between 10° C. and 40° C. were selected for observation.

The first set of experiments was made on February 23, the chart,[2] fig. 16, curve *A* being obtained in the morning and fig. 17 in the afternoon. The day was cold, with snow covering the ground. The blue-opaque curve *A*, fig. 16, virtually reproduces fig. 15; but the curve fig. 17 differs from it, inasmuch as the tangential angles in the latter case are steeper, so that the locus is less curved and rises higher than in figs. 15 or 16. In all cases yellow opaque lies above blue opaque. I was at first inclined to refer this to differences of the vanishing standard, believing the two curves to contain consistent observations, but differing from each other for reasons purely subjective. Whether or not this is the case can only be found by comparison with succeeding series of observations, as will presently be seen. Taking the observations at their face value, the indication is less dust for the afternoon than for the morning. The curve *P*, found for artificially dusty air, will be described below. (Section 38.)

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[1] See Chapter II, section 18.

[2] The observations *F F'* in fig. 16 refer to filtered air and will be described in section 41.

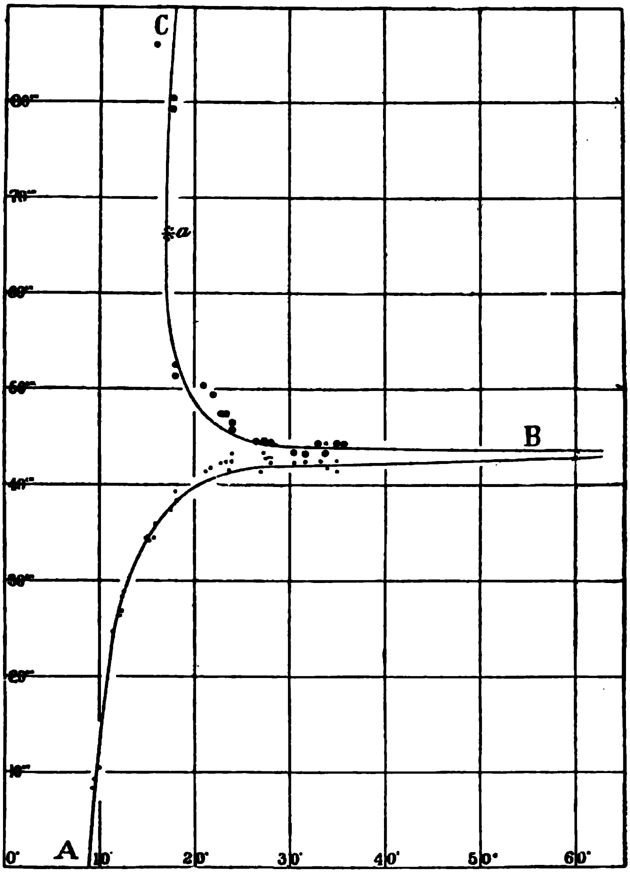


FIG. 18.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

35. *Further data.*—The next series of observations were made on February 27 (cloudy), 28 (rain), and on March 2 (clear). There was but little difference in the respective loci of the data, except that on the latter day the asymptote was somewhat below the position for the other days (see chart, fig. 18). The common asymptote takes a mean position (pressure, $p = 43$ cm.) between the corresponding values of figs. 15 and 16 ($p = 42$ cm.) and fig. 17 ($p = 48$ cm.).

36. *Further data.*—On March 3, however (see fig. 19), the asymptote rose again to the value of about $p = 46$ cm. The data here are not quite so uniform as in figs. 15–18, but the locus is none the less outspoken. The weather was cloudy, antedating the storm of March 4. Two series of observations were made. The prevailing warm weather prevented my taking observations at low temperatures. These new results induced me to conclude that the observations of figs. 16 and 17 might very well correspond to different states of the atmosphere.

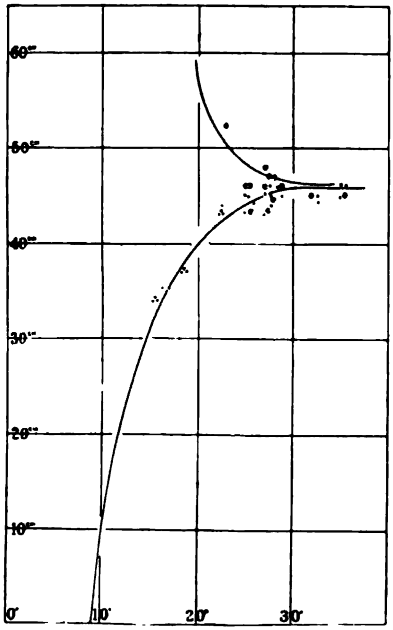


FIG. 19.—Chart showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

Finally, fig. 20 contains the results of March 6, 8, and 10, agreeing in character with fig. 18; while during the intermediate date, March 7, the locus fell to the lower position shown in fig. 21. These figures as a whole at least afford apparent evidence of the oscillation of the asymptote with the dust contents of atmospheric air. The observed interval of oscillation is within about 8 cm. of mercury pressure, but usually much below this.

37. *General character of the loci.*—Resuming the remarks of section 33, it is seen that when the asymptotes are high the loci as a whole show less curvature and the points between 20° and 30° C. tend to fall below the corresponding points for low asymptotes. I have endeavored to bring the whole phenomenon into a convenient equation, in which temperature and dust contents might appear as two variables by which the contours (pressure) of the margin of the opaque field (figs. 16 et seq.) are conditioned. The invention of a single form in which both the blue-opaque and the yellow-opaque margins are contained is more difficult than the fitting of a separate form for each curve, and possibly I have not been fully successful in any case. Cumbersome equations, or such as lead to involved computations, are of little interest for the present purposes, where the object sought is merely a terse and convenient epitome of the very large number of isolated observations which go to make up each of the curves in question.

I will here omit the earlier hyperbolic and exponential forms, each of which brought out some particular feature of the curves, and merely state a general form which (all things considered) probably reproduces my results within the limits of error.

Let p be the steam pressure actuating the jet, and t the temperature of the air into which the jet is discharged, and let A, B, C, n be constants to be presently discussed. Then

$$t = A\,10^{\frac{Cp}{(p-B)^n}} \quad \ldots . \ (1)$$

The quantity $(p-B)$ in (1) is always to be taken as a numeric—i. e., positively—otherwise imaginary results are encountered. Suppose, now, this equation is tested by the data of fig. 18, as these fairly represent a mean case Then

$p = 0$, $t = A = 9$, by observation;

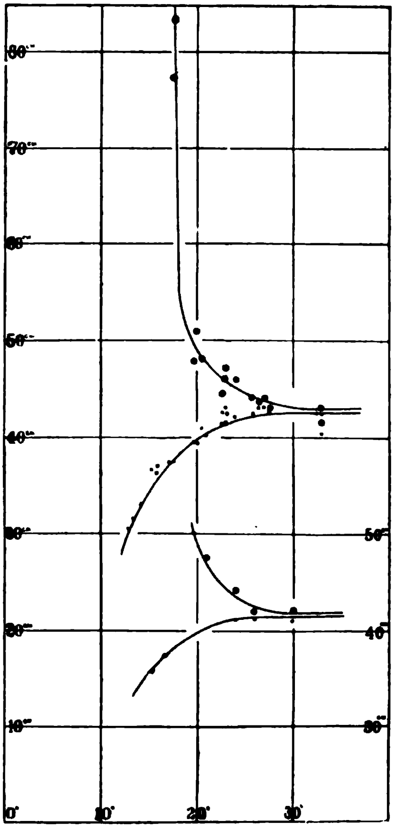
$p = B$, $t = \infty$, or $B = 43$, the height of the asymptote above the abscissa;

$p = \infty$, $t = \infty$.

Hence the yellow-opaque margin, lying quite above $p = B = 43$, corresponds directly to equation (1); whereas the blue opaque margin, lying quite below $p = B = 43$, corresponds to (1) with $(p-B)$ replaced by $(B-p)$. Furthermore, while in the yellow opaque branch p increases from 43 cm. to ∞, t passes through a minimum value. It is therefore necessary to inquire the position and character of this singular point. Let equation (1) be differentiated, remembering that $t = 0$ corresponds to $p = -\infty$, and therefore does not enter the present problem, and that $B = p$ has already been disposed of. Then the pressure p_m, corresponding to the minimum temperature t_m in question, is found to be

$$p_m = \frac{B}{1-n},$$

and the somewhat more involved expression of t_m is found from equation (1).



Figs. 20 and 21.—Charts showing the margins of the opaque field in terms of the actuating steam pressure and the air temperature.

With these preliminaries, the remaining constants C and n are then easily enough, though somewhat tediously, obtained from the observations making up fig. 18, by trial. The results are as follows:

TABLE 4.— *Computed margin of the opaque field.* $t = A\ 10^{\frac{Cp}{(p-B)^n}}$

$A = 9;\ C = 0.013;\ n = 0.35;\ B = 43.$

[Steam-pressures, p, in centimeters of mercury; air temperatures, t, in degrees C.]

Blue opaque.		Yellow opaque.	
$p = 0$ cm.	$t = 9.0°$	$p = 43$ cm.	$t = +\infty°$
10	9.8	44	33.6
20	11.0	47	21.4
30	13.0	50	19.2
40	20.3	[1]66.2	[1]17.4
42	31.6	70	17.4
42.8	85.3	90	18.1
43	$+\infty$		

[1] Minimum.

This curve, equation (1), has been inscribed in fig. 18, to show the grouping of the observations around it. The minimum is marked at a ($t_m = 17.4$°C., $p_m = 66.2$ cm.). Throughout the extent of the figure it unites two sufficiently flat curves to fairly represent the observations; for this part of the margin, from its exceedingly steep ascent, can not be traced with precision.

As a whole, therefore, equation (1) has reproduced the complete phenomenon surprisingly well, both as regards the blue opaque ($A\ B$) and the yellow opaque ($B\ C$) margin of the opaque field. No doubt better agreement could be had on further trial, particularly by varying the point of intersection with the abscissa $t = A$. I shall not, however, do this here, since in the present paper the chief datum is the height of the common asymptote ($p = B$) above the abscissa. It is this parameter which expresses the dust contents of the air, and which fortunately may be obtained without computation by the direct observations presently to be more fully specified.

38. *Artificially dusty atmospheres.*—To interpret the above data it is necessary to increase the dust contents of the normal atmosphere artificially, utilizing the tube F, fig. 14, containing phosphorus. The results for this case are not without complexity, but the character of the effect produced is obvious at once—it takes but a trace of phosphorus-tainted air to make the field permanently opaque at all pressures and temperatures not unreasonably high. In other words, the tendency is to drop the blue-opaque curve of the above figs. 15 to 21, into coincidence with the abscissa. One would surmise that at least the asymptotic portion of the yellow-opaque curve would likewise drop to the abscissa, and this is actually the case, as will be shown presently. By allowing the discharge from F to take place into E through a glass tube, only 0.6 cm. (less than one-fourth inch) in diameter, while the air tube *C* is fully 2 inches in diameter, I was able to dust the air sufficiently to obtain at least the approximate contours of the corresponding relation of steam pressure and air temperature. The data are inscribed in fig. 17, and together they make up the curve *P* near the axis of temperature. Thus the striking potency of even traces of dust is well exhibited.

Clearly the rudimentary curve *P* is a member of the same family to which *A B* belongs, and it is therefore obvious that the whole vertical distance between *B* and the abscissa is a region of temperature and pressure loci, each of which corresponds to a particular value of dustiness. Since, therefore, the accuracy with which the point can be located at any (mean) temperature is about 1 cm., the apparatus ought to register about 40° of dust contents between normal atmospheric air and the artificial mixture stated. On this scale the variation of the dust contents of normal air lies in the interval between 40 cm. and 50 cm. of mercury, remembering that the height of the asymptote (virtually reached at 28° to 30°) is taken for registry.

39. *Cold and warm phosphorus.*—To bring out the conditions more fully, however, it is necessary to make supplementary tests both with phosphorus and with filtered air.

If the basket of phosphorus is placed in the tube *E* (fig. 14), near its mouth *d*, where the air temperature (in winter) is near the freezing point, no effect is produced. Thus at 21° to 22° the blue-opaque margin was at 41 to 42 cm., showing that the oxidation at zero is relatively negligible in spite of the current of air.

If, however, the same phosphorus be placed in the tube *E C*, at *i*, somewhere between the point of confluence and the color tube, and where the temperature is, say, 20°, then it is actually possible to obtain the yellow of the first order at steam pressures less than 1 cm. Thus at 19° the yellow-opaque margin was at 1.2 cm., and the color persisted with increasing brilliancy at all pressures above this.

For temperatures greater than 20°, the tube is yellow at all pressures, until eventually above 35° all color vanishes for want of supersaturation.

For temperatures below 20°, the tendency is to produce opaque fields. Thus at 15° the tube is opaque at all pressures above a few millimeters.

The explanation of this somewhat puzzling behavior is this: At any given admissible temperature the effect of phosphorous dust is a change of the color of the field in the direction from blue through opaque to yellow in proportion as more dust is added. Again, the dust contents of the air passing over a given lump of phosphorus decreases both with the rapidity of the current and with the degree of cold. Hence at higher temperatures than 20° brilliant brown-yellow fields are the usual occurrence when the phosphorus lies in the air tube *C*. If withdrawn from the air tube and so circumstanced that its exhalation is diluted with much air (tube *F*, fig. 14), then any color may be produced, depending on the degree of dilution. On the other hand, below 20° the oxidation takes place more and more slowly, so that only very gentle currents of air can carry off enough dust to produce a yellow field. For strong currents in *C* there is a double source of dilution, and opaque fields are the rule. In other words, the air now approaches the state *A B* in fig. 17, so far as dust contents are concerned.

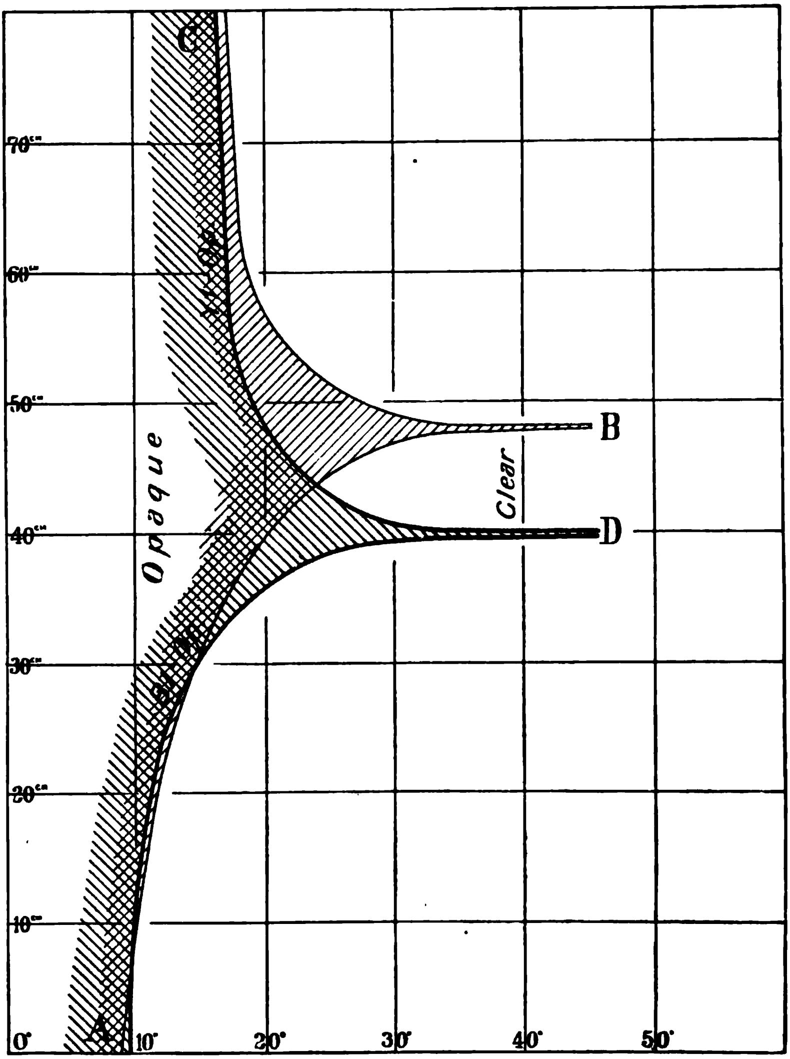


FIG. 22.—Variation of the opaque margin due to a change of dust contents. Diagram.

I have entered this subject at length because of its important theoretical bearing, seeing that it is necessary to disentangle a series of involved relations.

40. *Effect of dust contents.*—In fig. 22 (diagram), the pair of curves *A B C* indicates the margin of the opaque field for unusually pure atmospheric air. Above the horizontal asymptote through *B* there is a symmetrical disposition of browns, oranges, and yellows, the order of colors decreasing upward. Below *B* the colors are blues, greens, and hues of higher orders. The whole field to the right of *A B C* is colored merging into colorless; the field to the left of *A B C* is opaque.

As the air becomes more and more dust laden the yellow territory encroaches on the blue, so that for unusually dusty atmospheric air the pair of curves *A B C* has changed into *A D C*.

In the same way the yellows will continue to advance upon the blues for each successive (now artificial) increment of the dust contents of the air, until eventually the blues have been quite crowded out of the field and the whole territory is persistently yellow at all temperatures and pressures. In other words, the asymptote of the curve descends with increasing dust contents, while at the same time the curve *B C* moves bodily to the right, so that *B C* finally coincides with the coordinate axes of pressure and temperature. This at least is the essential feature of the phenomenon so far as I now understand it. Subsidiary details will be brought forward at some other time.

It is to be remembered that the particular curves, figs. 15 et seq., apply primarily to the particular jet discharging into the given tubes. Nor can any attempt as yet be made to graduate the apparatus; for a comparison with the Aitken dust counter (as has already been stated) is not legitimate, unless it can be proven that any given class of particles occurs proportionally to the total number—certainly a hazardous hypothesis. For the present the height of the curve above 28° (asymptote), expressed in centimeters of mercury pressure, is the empiric dust indicator.

41. *Filtered air. Small apparatus.*—A grave difficulty is encountered in using filtered air, inasmuch as the supply can not be obtained in sufficient quantity without employing very cumbersome apparatus. I have helped myself provisionally by using a tin tube *G*, fig. 14, with the end *n n* large enough to fit snugly into the air hole *C* when the heater is removed. *G* is filled with cotton throughout about 20 cm. of its length in the usual way. The end *n n* is closed with a sieve of brass-wire gauze, while the end *m* is closed with a perforated rubber cork, through which an influx tubulure, *o*, projects. This is connected with an ordinary oxygen tank, containing highly compressed air.

When the tube *C* (fig. 14) is closed with the filter *G* (no gas passing through it), the field of *A A* at once becomes clear. At the same time, however, its temperature rises to the boiling point, and the absence of color in this case is as much the result of insufficient supersaturation as of absence of dust. Now let the compressed air be admitted, so that the tube *A A* is considerably cooled. If the steam pressure is high enough, and the gas in sufficient quantity, the field first clouds over and then turns quite opaque. Thus, at a pressure of 50 cm. and a temperature registered at *t* of 47°, such a result (opaqueness) was obtained. At 30 cm. steam pressure the field turned cloudy, but opaque; at 15 cm. no clouding was even apparent. Colors were not observed in any case.

In view of the insufficient air supply obtained in case of the filter *G*, I replaced it by the form *H*, differing from *G* in having a drum much larger in diameter (length 25 cm., diameter 15 cm.), and special sieves *r r* and *s s*. Similar parts are similarly lettered. Under like conditions, such a filter should supply nine or more times as much air as the other (*G*).

The absorbent cotton inserted between the sieves *s s* and *r r* (the former and the lid being removed and the latter [*r r*] soldered in place) was carefully laid in layers parallel to *r r*, quite filling the width of the drum. When full to the top, the cotton was compressed by the second seive *s s*, which thereafter was also soldered in place, the lid with the inlet pipe *o′ m* soldered on, and the space between lid and *s s* filled with loose cotton to catch dirt. The compressed charge between *s s* and *r r* mainly acts as the filter. When not in use it was heated, so as to be thoroughly dry.

In the first experiments with the filter *H*, compressed air (issuing as usual from a narrow pipe, and at a tank pressure of about 15 atmospheres) was used as before. Spreading through the filter, the air enters the color tube at a much reduced velocity. As the air in the tank is gradually freed from dust by the subsidence of the latter, there is here an addition means of purification. But the method is much too lavish to be practical, even if it be conceded that the filter is actually efficient. The following data were thus obtained at temperatures comparable with the values in the charts. Colors were not observed:

Temperature	20°	21°	22°	23°	33°	C.,
Pressure	41.5	42	43	44	58	Cm. Hg.

In the set of data for 20° to 23° the filter was not so well packed as at 33°. Observations were discontinued for want of gas. I have inserted these data in the chart, fig. 16, at *F* and *F*′. When taken together, they suggest a locus of the same nature as fig. 17—i. e., implying less curvature in proportion as the air is less dusty. Bearing this in mind, the margin of the opaque zone at 20° for filtered air is not as much above the atmospheric curve as one would anticipate. It follows that the size of the particles producing colored cloudy condensation in atmospheric air is not necessarily enormous when compared with molecular diameters, an inference which I have already drawn[1] both from the character of the color phenomena and from the conditions of condensation. Cf. Chapter II, sections 22, 27.

42. *Filtered air. Large apparatus.*—Having obtained these preliminary results, I attacked the subject on a much larger scale, using an apparatus very similar to fig. 14 (with the phosphorus tube removed), except that the air, instead of being taken out of the atmosphere at *c* and *d*, passed at those points through two large filters of the type *H*, fig. 14. A large Root blower, actuated by a 1-horsepower gas engine, forced the air through the system.

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[1] Am. Meteo. Jour., IX, pp. 507, 519, 1893.

Contrary to my expectations, this arrangement remained to the last utterly inefficient. When the blower acted under low pressures, the air entering the color tube was insufficient in quantity. For higher blower pressures and a more rapid current of air[1] the evidences of filtration were practically absent. It was easy to trace the increase of dust contents with the velocity of the current of nominally filtered air, even though high speeds were excluded by the nature of the case. The nozzle of the original steam jet being 0.16 cm. in diameter, I replaced it by a finer one, 0.09 cm. in diameter, but without advantage. It is noteworthy that for atmospheric air both these jets gave identical results as to the location of the opaque margin near the asymptote. The colors for the fine jet were fainter, and together with the opaque field vanished at a lower temperature, as one would suppose, seeing that only one-third as much steam is available in one case as in the other.

The best results for filtered air are, therefore, those of the preceding paragraph. A sufficient degree of supersaturation presupposed, in no case was there an absence of condensation, but, as I can not assert that the air used was rigorously pure, it does not follow that I have reached the conditions[2] under which the molecules themselves act as condensation nuclei. Were this the case, then the supersaturation at the lower margin of the opaque field, expressed either isothermally as pressure or isopiestically as temperature, leads easily to the molecular dimension. For the margin in question is a locus at which the issuing steam condenses as a whole, or in which the vapor contains within itself the conditions of condensation.

43. *Apparent variation of dust contents of normal air.*—In conclusion I shall summarize my results for the observed changes of the dust contents of normal atmospheric air, expressing this datum by the height (steam pressure in cm. of mercury) of the asymptote of the margin of the opaque field, at a temperature near 30° C., of the inflowing air. The observations for earlier dates are necessarily somewhat crude and sporadic, for in work of this kind it is difficult to arrive at a fixed personal equation at once. The apparatus, moreover, was imperfect in one or more of its early details. The air taken in at the center of the Smithsonian Park is probably as normally atmospheric as can be had in Washington.

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[1] Compare this with the similar experiences of Mr. Aitken, in Trans. Roy. Soc. Edin., xxxv, p. 11, et seq., 1888.

[2] The delicate question of purity comes into play in the other researches. Thus condensation apparently without nuclei was produced by Aitken (Trans. Roy. Soc. Edin., xxxv, p. 16, 1888), using the expansion method. R. v. Helmholtz failed to obtain it for exhaustions up to one-half atmosphere (Wied. Ann., xxvii, p. 521, 1886), whereas Aitken's exhaustions were only to three-fourths atmosphere (loc. cit, p. 8.)

TABLE 5.—*Dust contents on successive days—i. e., pressures actuating a steam jet discharged into normal air, between 28° and 32°, when the blue color field passes into opaque.*

Date.	Pressure.	Date.	Pressure.	Date.	Pressure.
1893.	*Cm. Hg.*	1893.	*Cm. Hg.*	1893.	*Cm. Hg.*
Before February 23..	40	March 10, p. m.....	42.5	March 18, a. m.....	42
February 23, p. m...	48	March 11, a. m.....	42	March 18, p. m....	41.5
February 24.........	43.5	March 11, p. m.....	42.5	March 19, a. m....	42
February 25.........	43.5	March 12, a. m.....	42	March 20, a. m.....	42.5
February 27.........	43	March 13, a. m.....	43	March 20, p. m.....	42
February 28.........	43	March 13, p. m.....	43.5	March 21, a. m.....	42
March 2.............	43.5	March 14, a. m.....	43	March 21, p. m.....	42.5
March 3.............	46	March 14, p. m.....	42	March 22, a. m.....	41
March 6.............	42	March 15, a. m.....	42	March 22, p. m.....	42
March 7.............	42	March 16, a. m.....	43.5	March 23, a. m.....	41
March 8.............	43	March 16, p. m.....	43.5	March 24, a. m.....	40.5
March 10, a. m......	43	March 17, a. m.....	43		

The results are shown graphically in fig. 23, where the dates are laid off as abscissas and the dust contents (expressed in pressures as above) as ordinates.

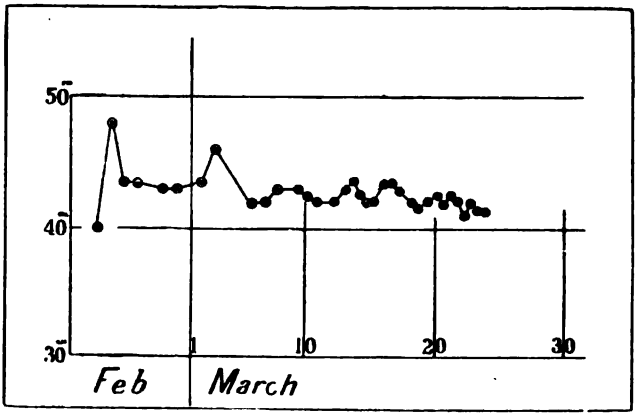

FIG. 23—Diurnal variations of dust contents (empirically rated) of normal atmospheric air.

The chart contains about a month's observing, and in its general features calls to mind Mr. Aitken's "dust curves," remembering, however, that in fig. 23 the ordinates grow with increasing purity. Throughout the month the dust contents of the air do not depart very often from their normal value, and the fluctuations are usually characterized by a suddenness (relatively speaking) of appearance. Thus marked changes of dust contents may take place within fractions of a day. In general the air has been gradually getting less pure between February 23 and March 23.

I endeavored to put these data into correspondence with the meteorological elements of the time of observation, and I also availed myself of the comprehensive digest which my colleague, Prof. F. H. Bigelow, has constructed; but the time during which the above observations were taken is far too short to make such comparisons fruitful. The object of fig. 23 is therefore merely to exhibit the character of the results obtained and the degree of efficiency of the above apparatus and not to attach any ulterior meaning to the results themselves. Section 47.

44. *Continuation.*—A similar series of observations made during the ensuing month is given in Table 6. During the first two weeks of this time the dust contents retain the degree of constancy as referred to in section 43, showing slight fluctuations around a mean value. After this (on April 6) the jet was used in certain experiments which kept it in action for about half a day. The table shows the effect of this treatment to be very marked and in the direction of an increase of apparent dust contents. The jet, moreover, never recovered its normal standard, proving clearly enough that the nozzle had in some way been permanently altered. Inasmuch, therefore, as an increased roughness of bore is equivalent in its relation to the jet to an increase of dust contents, the discrepancy observed can only be due to an appreciable amount of corrosion of the brass nozzle by the issuing steam. Thus a general inquiry as to the magnitude of the distortion which would follow from the use of improperly shaped nozzles was called for, and the investigation could now be made with considerable certainty, since the laws of the phenomena for a given jet were understood.

TABLE 6.—*Dust contents on successive days, etc.*

[Continuation of Table 5.]

Date.	Pressure.	Date.	Pressure.	Date.	Pressure.
1893.	*Cm. Hg.*	1893.	*Cm. Hg.*	1893.	*Cm. Hg.*
March 24, p. m	40.5	March 30, p. m	41	April 5, a. m	41
March 25, a. m	41	March 31, a. m	41.5	April 5, p. m	42
March 25, p. m	41.5	March 31, p. m	40.5	April 6, a. m[1]	41
March 26, m	41	April 1, p. m	40.5	April 6, p. m	39
March 27, a. m	40.5	April 2, p. m	41	April 7, a. m	39.5
March 28, p. m	41	April 3, a. m	42	April 7, p. m	38.5
March 29, a. m	42	April 4, a. m	40.5	April 24, a. m	38
March 29, p. m	42	April 4, p. m	40		

[1] After allowing steam to rush through the nozzle for half a day.

45. *Bore of the nozzle.*—In the experiments thus far, no particular mention has been made of the bore of the nozzle, excepting, perhaps, the few remarks (sections 32, 42) which refer in a casual way to dimensions. But the character of the bore is a datum of marked importance, and I have therefore spent much time in looking into the details of this question from the hydraulic point of view. With the aid of the koniscopic dust counter, just described, definite results may now be obtained by noting the pressure at which blue-violet field passes into opaque, at given temperatures of the inflowing air; or, more simply, by noting the mean pressures at which the blues change to yellows in the neighborhood of 30°.

The diversity of results obtained in this way for different nozzles is startling. The following data are selected at random from my notebook, θ being the air temperature at influx, and p the mean pressure corresponding to the blue opaque field.

TABLE 7.—*Showing the effect of rough nozzles.*

Number.	θ.	p.	Remarks. Diameter of bore, 0.09 cm.
	°	*Cm.*	
I	30	41	Newly drilled and smoothed.
II	32	42	Do.
III	32	36	Do.
IV	32	38.5	III polished with steel tool.
V	31	34.5	Newly drilled.
VI	28	33	Brass plate, 3 mm. thick, newly drilled.
VII	29	41.5	Same; hole polished at both ends with emery.
VIII	30	46	Brass plate, 1 mm. thick; hole polished on both sides with emery.
IX	30	31.5	Platinum plate, two holes newly drilled; plate 2.5 mm. thick.
X	30	29	Same; holes reamed out with a needle.
XI	32	40	Same; hole polished at both ends with emery.
XII	30	45	Same; further polishing.
XIII	30	30	Another platinum plate, newly drilled.
XIV	30	37.5	Same; polished with emery.
XV	30	46	Same; further polishing.

Similar results (pressures ranging from 30 cm. to 44 cm.) were obtained with a larger bore 0.15 cm. in diameter. Thus there is no certainty that the size of the hole has an influence, since in any case an apparently insignificant roughness in the bore may change the condensation pressure (blue yellow) from 30 cm. to almost 50 cm. at 30° C. This is one of the grave difficulties of the koniscopic method proposed, for it is obvious that if the roughness of bore increases by corrosion or otherwise in the lapse of time the effect would be interpreted as an increase of dust contents. The nozzle should therefore be made of platinum. Glass nozzles are liable to break and difficult to fasten in place, and they are otherwise not superior to metallic nozzles.

The most effectual method of polishing the holes after drilling and smoothing consists in passing a piece of cotton twine saturated with oil and emery flour through the hole, and then wearing the latter down gradually, especially near the edges. All my endeavors to use steel reamers for the same purpose failed.

46. *Sensitiveness.*—When a nozzle has been made very smooth so that the condensation pressure (blue yellow at 30° C.) is above 45 cm. of mercury, it does not follow that the apparatus so obtained is sensitive to an equally marked degree. Indeed, the reverse seems to be the more usual case. Thus in the neighborhood of $p = 45$ cm. the transition from blue to yellow takes place within a pressure of 2 or 3 cm. of mercury, whereas below $p = 40$ cm. the transition is often complete within 1 cm. The most sensitive jets were always obtained without polishing. Thus a single hole 0.09 cm. diameter gave a blue field at 41.5 cm. and a yellow field at 42.5 cm. when the influx was at 32°. At the same medium temperature, two similar holes, about 0.4 mm. apart, showed a blue field at 39 cm. and a yellow field at 40 cm.; but I have not hit upon any sure method of producing these results in all cases. If the hole is too fine in bore, the colors are apt to be too faint. If the hole is too large, the opaque field is too intense and the colors too muddy. I should say that the duplex nozzle just described gave the best results.

The position of the nozzle in the color tube is also an item of importance. It should lie slightly below the axis of the influx pipe, but not above or below its upper or lower tangential planes. So far as possible the nozzle should squirt axially upward into the color tube.

There are a number of subsidiary results which may be added here, inasmuch as they throw light on the phenomenon in question. By allowing jets to play into color tubes of different widths, no change of the condensation pressure was observed, other conditions remaining the same. Thus the nozzle 0.09 cm. in diameter showed $p = 41$ cm. for $\theta = 30^\circ$ in a tube 5 cm. in diameter, and the same values of p and θ for a tube 8 cm. in diameter, the influx pipe for air being the same in the two cases. A like result was obtained for jets 1.5 cm. in diameter.

Similarly, in case of a brisk flow of steam, the length of the pipe conveying the steam to the jet has no effect, nor is an evident advantage gained by jacketing this pipe. Pipes as long as 100 cm. and more were tested.

Finally, the temperature of the color tube is without influence. If a fine sheet of cold water is allowed to run down the outside of this tube, the only obvious effect is a greater faintness of color due, to condensation. The condensation pressure and temperature do not perceptibly change (cæt. par.). Thus in case of a drenched tube $p=41$ at 28°, and in case of the same tube not cooled $p=41$ at 29°—i. e., there is no evidence that the effect of cooling the color tube is anything beyond an additional condensation of steam.

There is sometimes an observable fall of the pressure p with the time during which the jet has been in action.

Premature condensation may often be counteracted, wholly or partially, by increasing the current of air.

47. *Conclusion.*—It follows from the remarks made in section 46 that each jet has a certain hydraulic individuality, which does not change so long as the nozzle is not changed either by corrosion or otherwise. At the same time the contours of the margin of the opaque field are alike in kind for all nozzles. Increments either of the dust contents of the air or of the roughness of the bore have a similar and mutually replaceable tendency to change the steady motion of the jet into eddying motion and thus to usher in the opaque field, followed by yellows of the first order.

I conclude from tables 5 and 6, interpreted in the light of the present and preceding results (sections 38, 39), that the excessively fine dusty constituent of the air—i. e., those particles which give rise to colored cloudy condensation, and are therefore virtually visible by interference methods—is a fixed attribute of normal atmospheric air and is invariable as to quantity.

[This unexpected and yet necessary conclusion of the experiments of the present chapter may possibly be interpreted in relation to Bidwell's discovery (section 11), viz, that actively dusty air largely loses its precipitating power on keeping in a closed vessel.—Feb. 2, 1895.]

CHAPTER IV.

THE THERMAL TOPOGRAPHY OF THE FREE STEAM JET.

PURPOSES OF THE WORK.

48. *Nature of the problem.*—If the steam jet is to be used as an instrument of research, and in the manner which the foregoing chapters have pointed out, then it is necessary to have a minute knowledge of the distribution of temperature throughout its length and breadth. The law expressing this distribution is therefore first to be investigated for any given conditions. It is then necessary to find how this law changes, both with the temperature of the medium of air into which the jet is discharged and with the pressure actuating the flow of steam. Finally, the effect produced when the jet is surrounded by a suitably ventilated tube is to be shown, and the distribution in this case compared with the results for the free jet. It appears from the above pages that when the color tube is used condensation is promoted or retarded by the temperature of the inflowing air in a well-marked manner, and it is thus through the color tube that the nature of the medium-constant is most clearly apprehended.

49. *Pressure and volume.*—In addition to temperature, the distribution of pressure and volume throughout the steam jet are important desiderata, for these are the variables which must be known if the isothermals are to be traced experimentally. The instrument for the measurement of pressure at any point is not yet forthcoming; much less is it possible to determine the volume which obtains for the given point. All such experiments are made doubly difficult by the rush of the condensing steam from an orifice. There is, therefore, an essential incompleteness in the measurements made upon steam jets, and a part of the conclusions reached must remain inferential.

On the other hand, condensation as seen in the steam jet is virtually steady and so clear cut in its nature that whatever information can be obtained of the details of the phenomenon can not but be important. It is for this reason that I have gone extensively into the question of temperature distribution, as shown in the following paragraphs.

50. *Literature.*—I have found nothing in the literature of the subject sufficiently precise in its nature to be available for the present purposes.

APPARATUS.

51. *Jet.*—The nozzle of the jet in these experiments was similar to those above used, except that special means were provided for attaching and moving the thermocouple. In fig. 24 one end of the tube *a b* communicates with the steam box (which in the present work was made wholly of gas pipe, being stronger and of smaller capacity than the one shown in fig. 6). The other end of *a b* carries the short tube *c*, with a hole at *n*, from which the jet is to issue. The cap *d d* closing the outer end of *c* makes with it an ordinary stuffing box, by which the insulator *f* of one junction of the thermocouple is secured in place. Thus the temperature of the steam may be measured at *e*, immediately before leaving the nozzle *n*.

The other and movable end of the thermocouple is adjusted by means of a suitable clamp, *k*, free to slide up and down the standard *g*. In this way the insulator *h* of the couple may be so placed that the junction *i* takes any desirable position above the nozzle *n*, and the height of *i* above *n* is read off on a scale, *S S*[1], etched on mirror glass, placed vertically behind the jet. By keeping the images of the eye and of the junction in coincidence, increments of height may thus be read off as closely as necessary. It is not so easy to fix the junction in the axis of the jet.

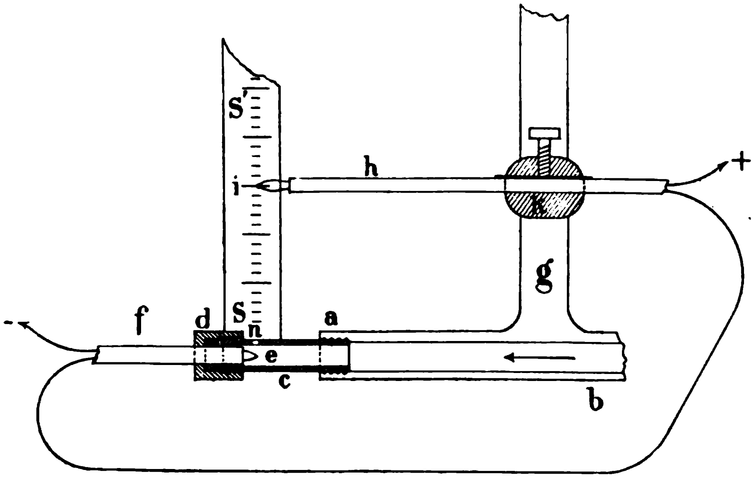

FIG. 24.—Free steam jet with attachments, etc.

The slide *g* is rigidly attached to the tube *a b*. When temperatures are to be taken across the jet, *g* is replaced by a horizontal slide corresponding to a horizontal scale, *S S*[1].

When the junction *e* is not used, the cap *d d* is replaced by a tube and stopcock bent vertically downward; for by keeping this cock slightly open the water condensing in *a b* is discharged, and the annoyance of drops choking the nozzle *n* is obviated. Possible changes of temperature produced by the additional aperture are not to be overlooked.

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[1] Cf. Bulletin U. S. Geological Survey, No. 54, p. 95 et. seq., 1889.

All parts of the steam box and the conveyance tubes are to be properly jacketed with blanketing, so as to diminish loss of heat by radiation.

52. *Temperature measurement. Thermocouple.*—The thermocouple is the only apparatus available for the present work. I made use of thin wires of German silver and of copper, soldered together at as fine a point as possible. The wires were kept apart by insulators of fire clay,[1] leaving only the junction exposed, as shown in fig. 24. Where measurements (as in the present instance) are to be made by the galvanometer, the resistance of the couple is a consideration. Hence I constructed half couples, as they may be called, containing a single junction between a meter length of copper wire and a half-meter length of German-silver wire. The free ends of the copper wires were always to be used as the terminals of the couple, and therefore led to the galvanometer. The free ends of the German-silver wires were soldered together when any two points were to be thermally compared. Thus, by putting a junction in the steam box, another below the steam nozzle (as shown in fig. 24), a third in the jet (also shown in fig. 24), and a fourth in a normal boiling point apparatus, I had the means of finding the difference of temperature between any two of these points.

53. *Temperature measurement. Galvanometer.*—To measure the thermocurrent produced, I made use of my torsion galvanometer.[1] In this instrument the needle is kept in a fixed plane parallel to the winding and all current expressed directly in terms of the torsion of a platinum fiber. If D be the amount of twist observed when the temperature of the junctions of the thermocouple are respectively T and t, then

$$D = a(T-t) + b(T^2 - t^2) \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

a well-known equation, in which a and b are constants. Remembering that the resistance of the circuit is constant, and is largely (almost wholly) in the coils of the galvanometer, a calibration is to be made once for all, by finding the values of D when the temperatures of the junctions are known. In this way a and b were computed and found to be (at a temperature of the galvanometer of 10°)

$$a = 0.8967; \; b = 0.001167; \; c = \frac{b}{a} = 0.0013.$$

These constants necessarily vary, and vary in marked degree when the temperature of the coils changes, for a greater resistance is now introduced and the elastic and magnetic constants are no longer the same. But the effect of this is to alter the constants a and b individually; it can not alter the relation $\frac{b}{a}$, since this depends only on the couple. Hence, if equation (1) be expressed

$$D = a(T-t)(1+c(T+t)) \quad . \; . \; . \; . \; . \; . \; . \quad (2)$$

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[1] Barus: Bulletin U. S. Geological Survey, No. 103. Cf. "Behandlung u. Messung hoher Temperaturen," p. 82; Barth, Leipzig, 1892.

where c is known, only a single measurement suffices to determine the new value of a. Thus the recalibration is simple, for it is merely necessary to put the hot junction in steam and the other in cold water of known temperature to find the appropriate a for the day.

In this way during the course of some three months I found temperature 10°, $a = 0.897$; 16°, $a = 0.880$; 20°, $a = 0.867$, showing the temperature coefficient to be about -0.003 per degree Centigrade. For ordinary accuracy, therefore, recalibration is also superfluous, since the oefficient is known.

Finally, to measure temperature by the aid of (2) one of the values T or t must be known, and the other is therefore given by the equation. The work is facilitated by writing this equation

$$D + at + bt^2 = a\,T + b\,T^2,$$

or

$$D + f\,(t) = f\,(T),$$

and computing a table for the function $f\,(t) = at + bt^2$.

RESULTS.

54. *Notation.*—The results obtained are given in the following tables (8 to 10) in a way showing how the method was gradually perfected. Two commutations at the torsion galvanometer were made for each temperature measurement. Consequently each datum for temperature is the mean of three observations, corresponding to three readings for the actuating steam pressure (P) also averaged.

This premised, P denotes the pressure of the steam in the steam box directly observed in centimeters of mercury. P is therefore properly the excess of the steam pressure above the atmospheric pressure. T^1 denotes the corresponding boiling point of water taken from well-known tables[1]. T is the temperature just well inside of the nozzle of the jet, computed from observations given in section 61. Finally, t is the temperature sought—i, e., the temperature at an axial point of the steam jet H cm. above the nozzle for the given temperature, θ, of the medium of air into which the steam discharges, and the actuating steam pressure (steam box) P.

As a rule the difference of temperature between the steam box and the divers points of the jet was directly measured thermoelectrically. In this case, if the Avenarius-Tait equation of the thermocouple be put

$$f\,(T) - D = f\,(t), \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

where D is the observed twist and the functionality $f\,(T) = a\;T + b\;T^2$; and where a and b are the constants measured and corrected as shown in section 53—then since D is directly observed (torsion galvanometer) and T is known through P, the quantity $f(t)$ is also known, and therefore t is easily derived. Thus, it is merely necessary to construct a table for the function $f\ (T)=a\,T+bT^2$ between about 0° and 150°, graphically, and to construct a similar table for the vapor tension of water between those limits, to have in hand the apparatus for the easy computation of the temperature t at any specified point of the steam jet.

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[1] Cf. Landolt u. Boernstein: Phys.-chem. Tabellen, pp. 40–46, Berlin, 1883.

With the object of introducing desirable variations of method, I occasionally measured the difference of temperature (galvanometer twist D) between the inside of the nozzle and the points of the jet. In such a case T in equation (1) must be replaced by T^1 already defined.

Again, I measured the difference of temperature between the steam of a normal boiling point apparatus and the points of the jet. Here G is to be replaced by T'', the boiling point of water for the barometric height of the day.

55. *Earlier data.*—After the explanations given in the preceding paragraph, the data of Table 8 will be easily understood. The chart, fig. 25, belongs to this table. The table consists of four parts, A to D, containing different sets of observations, with a final summary of the chief results.

The first set under A is disappointing, for the variations (not on the chart) are cyclic. To find out whether this was really the case, I placed one of the junctions of the thermocouple in a boiling point apparatus, obtaining the data of the next set under A. The results so obtained are clear enough. They indicate a linear variation of the temperature at a given height ($H=0.4$ cm.) above the nozzle, with pressure P, the slope being 0.093 and the initial temperature ($P=0$), 94.6°.

The final set of data under A are corroborative. They show that the observed (thermoelectric) and the computed (from P) temperature of the steam box differ by 0.8° C., which, however, is nothing more than the temperature correction of the torsion galvanometer. Section 53.

TABLE 8.—*Change of temperature at a given axial point with the actuating steam pressure. Earlier results. Nozzle one-sixteenth inch in diameter.*

A. $H=0.4$ cm.[1]

P	T^1	T	t	$100-t$	$T-t$	$\frac{dt}{dp}$, t_0
Cm. Hg.	°C.	°C.	°C.	°C.	°C.	
10.0	103.4	102.6	90.5	....	12.1	(?)
31.0	109.7	108.8	91.2	....	17.6	....
74.3	120.3	119.1	86.1	....	[2]33.0	....
53.9	115.6	114.6	85.6	....	29.0	....
36.8	111.4	110.5	87.2	....	23.3	....
28.2	109.1	108.2	88.2	....	20.0	....
16.9	105.6	104.8	89.2	....	15.6	....
10.1	103.5	102.7	90.0	....	12.7	....

H 0.4 cm. $T''=100°$ C.[3]

22.0	107.4	106.6	96.7	−3.25	109.8	+0.093
39.6	112.3	111.4	98.2	−1.80	113.2	94.6°
52.5	115.4	114.4	99.3	−.70	115.1	....
82.8	122.0	120.8	102.6	+2.03	118.2	....

[1] Junctions in steam box and in jet.
[2] Cyclic change negative.
[3] Junctions in boiling-point apparatus and in jet.

TABLE 8.—*Change of temperature at a given axial point, etc.*—Continued.

Steam box and boiling-point apparatus. $T' = 100°$ C.[1]

P	T'	T	t	$100-t$	$T-t$	$\frac{dt}{dp}, t_0$
Cm. Hg.	°C.	°C.	°C.	°C.	°C.	(t)
14.3	104.7	103.9	105.5		— 0.8	
29.2	109.3	108.4	110.1		— 0.8	
49.2	114.5	113.5	115.3		— 0.8	
65.7	118.4	117.3	119.1		— 0.7	

B. $H=1.5$ cm.[2]

10.8	103.6	102.8	74.9		27.9	(0.071)
22.5	107.4	106.6	74.3		32.3	72.6°
35.3	111.0	110.1	74.3		35.8	
48.8	114.4	113.4	76.1		37.3	
62.5	117.6	116.5	77.4		39.1	
76.8	120.7	119.5	80.1		39.4	
73.3	120.0	118.9	79.5		39.4	
59.3	116.8	115.7	77.4		38.3	
45.9	113.6	112.6	75.6		37.0	
30.1	109.5	108.6	73.9		34.7	
16.8	105.7	104.9	73.8		31.1	

$H=3.8$ cm.[2]

12.4	104.3	103.5	58.2		45.3	(0.071)
27.7	108.8	107.9	57.5		50.4	56.2°
44.1	113.4	102.4	60.0		42.4	
53.0	115.5	114.5	60.4		54.1	
61.3	117.4	116.3	61.7		54.6	
40.9	112.5	111.5	59.5		52.0	
23.7	107.8	107.0	57.5		40.5	
11.7	104.0	103.2	56.5		46.7	

$H=8$ cm.[3]

9.3	103.2	102.4	44.4		58.0	0.071
22.3	107.4	106.6	45.5		61.1	44.1°
43.8	113.3	102.3	47.0		55.3	
68.2	118.9	107.8	49.4		58.4	
51.0	115.0	104.0	47.6		56.4	
29.6	109.5	108.6	46.5		62.1	
13.5	104.6	103.8	45.4		58.4	

C. $H=0.8$ cm. Medium $\theta = 30°$ C.[2]

9.0	103.2	102.4	80.4		32.0	(0.071)
20.8	106.8	106.0	80.5		25.5	(79.5°)
34.6	110.7	109.8	82.0		27.8	

$H=0.9$ cm. Medium $\theta = 27°$ C.[3]

9.8	103.4	102.6	80.6		22.0	(Negative).
23.3	107.6	106.8	77.0		29.8	
52.0	115.3	114.3	70.6		43.7	

D. SUMMARY.

$P=0$	$H=0.4$ cm.	$t_0=94.6°$C	$\frac{dt}{dp}=0.093$
$P=0$	$=0.8$	$=79.5$	[4] (0.071)
$P=0$	$=1.5$	$=72.6$	(0.071)
$P=0$	$=3.8$	$=56.2$	(0.071
$P=0$	$=8$	$=44.1$	0.071)

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[1] Junctions in boiling-point apparatus and in steam box.

[2] Junctions in steam box and in jet.

[3] Junction in steam box and in jet. Jet tube loosening?

[4] Data in parentheses are approximate, and inferred from the last value.

The data under *B*, for heights respectively $H = 1.5, 3.8, 8.0$ cm. above the nozzle, are more outspoken. The noncyclic linear character of the curves and the positive slopes are sustained more or less throughout, but particularly at $H = 8$ cm., when the jet is broader and the axial observations more certain. Initial temperatures and slopes are summarized under *D*.

C contains a few supplementary results for positions *H*, near the nozzle. The temperature θ of the medium is given. It is absent in the earlier work. The second set under *C* is again negative, like the first under *A*, showing the great difficulty in obtaining the temperatures very near the nozzle, where the jet is narrow. Section 60.

In the summary *D* the initial temperature t_0 at $P = 0$, in its dependence on the height above the nozzle is the interesting datum and is given graphically in the chart, fig. 25. Contrary to my expectations (for the temperature of the medium, etc., was not always taken), these values (t_0) form a curve of well-marked contour. I will discuss it below sections 59, 69, and here merely remark that at any height above the nozzle the character of the variations of the jet temperature (t) with the actuating pressure (P) is such that when P approaches zero t reaches a definite limit greater than zero, and definitely decreasing with *H*.

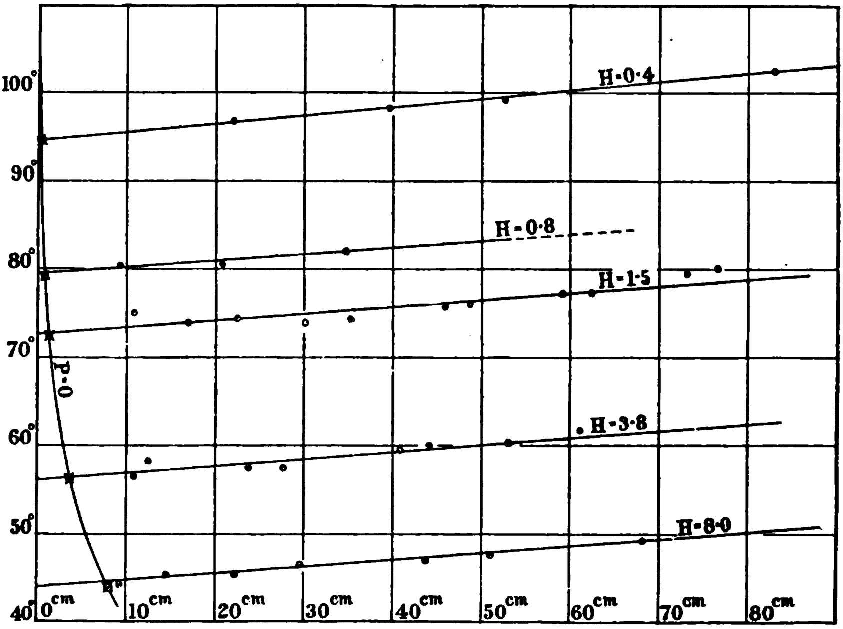


FIG. 25.—Chart showing the increase of temperature for different pressures actuating the steam jet.

56. *Errors.*—After these encouraging results I resolved to perfect the method, taking into account the chief causes of the discrepancies encountered. The occurrence of supersaturation in the steam box may be dismissed, for the steam tarries here for some time and the observations under *A*, Table 8, are proof against it. Similarly, progressive leaks in the pipes (a probability in case of the second set under C) are soon discovered. Drops are apt to condense on the thermoelectric junction and distort the results. The junction should be inclined so that drops may run off.

There remain three other chief sources of error—viz, the irregularity of the air temperature in a heated room in winter, its ulterior disturbing effect on the torsion galvanometer, and the difficulty in placing the junction axially in the jet. As for the room temperature, if the jet is to discharge freely into the air, the difficulty is well-nigh insuperable in winter, for cold-room temperatures alone are not sufficient to bring out the whole phenomenon. A season of variable temperatures and a room not heated are the desiderata, but which were not forthcoming during the course of my work. Perhaps a very wide vertical funnel shaped tube, with a narrower tubular opening in the bottom containing a thermometer to register the temperature of the inflowing air, and the jet axially fixed and playing vertically upward above the hole, might practically leave the surface conditions unchanged, but I have not tried it.

Aside from this, the chief error in the results of Table 8 is the insufficiently perfect axial adjustment of the thermocouple. This is proved by the fact that the curves tend to become smoother when the measuring junction is moved from points near the nozzle to the wider parts above. Where the jet issues its width is not much above one-sixteenth of an inch, and within this fine filament the radial distribution of temperature falls off from (say) 100° to (say) 20°. The upper parts of the jet may be 5 or even 10 cm. in maximum width. (Cf. section 58.) Again, an obstruction like the junction tends to deflect the jet unless everything is quite symmetrical. Hence, it is only natural that, with increasing pressure, the assymmetry should also vary. In this way the negative slopes of observations near the nozzle are sufficiently accounted for, as will be more fully shown in section 60. Temperatures near the nozzle are apt to be measured too low.

If the junction be too near the nozzle, the flow of steam is possibly diminished; but I do not think this difficulty has entered my work. The construction of the steam box is such that pressures must be the same at the tube of the manometer and at the junction of the thermocouple in the box. Instead of the pressures in the steam box, the computed pressures in the nozzle might have been given; but the former, being data of observation, are preferable.

57. *Further data. High temperature environment.*—Hence in my remaining experiments the slide supporting the thermoelectric junction was rigidly attached to the nozzle, and great precautions were taken to secure an axial adjustment. As a result, negative slopes have not again been encountered and the curves show greater smoothness and consistency throughout.

In Table 9 the medium is at the relatively high temperature $\theta = 26°$

to 27°. Under these circumstances the visible part of the steam jet was about 50 cm. long and 5 cm. in diameter. As Table 9 shows (data for P), the work was usually done cyclically, but the curves are not cyclic.

In the part A of the table the hot junction was in the steam box and its temperature therefore T', from which t is computed. In the part B the hot junction was placed in the jet tube just below the nozzle.

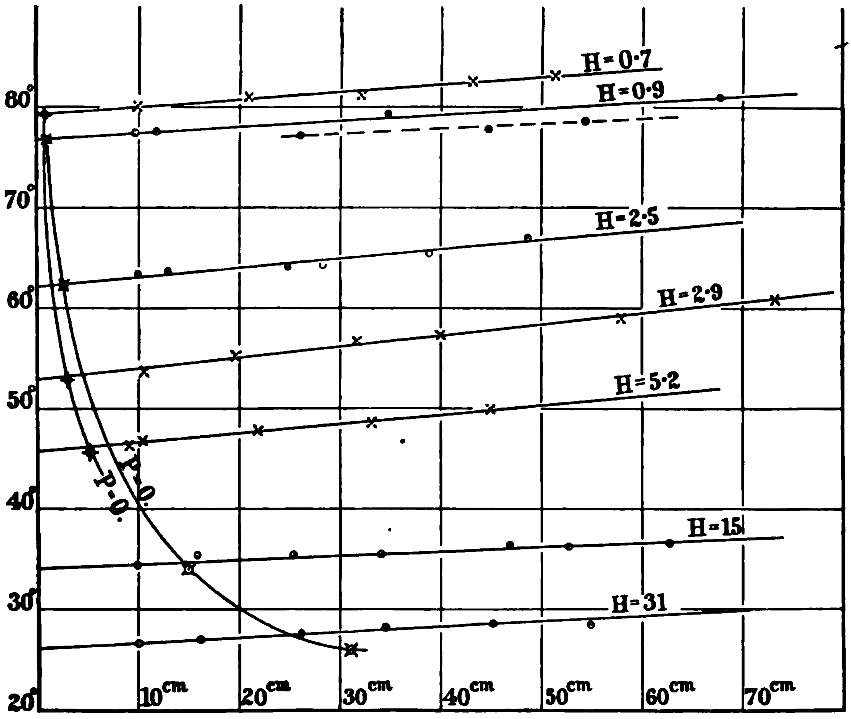
The chart Pl. I accompanies this table, and observations A are indicated by circles, observations B by crosses.

Table 9.—*Change of temperature at a given axial point of the jet, with the actuating steam pressure. Barometer 76 cm.*

P	T'	T	t	$T-t$	$\frac{dt}{dp}$, t_0
A. H = 0.9 cm. Medium 27° C.[1]					
11.5	104.0	103.2	77.6	25.6	0.060
25.9	108.4	107.5	77.2	30.3	76.8°
44.6	113.4	112.4	77.8	34.6	....
67.6	118.7	117.6	81.0	36.6	....
51.3	115.7	114.7	78.6	36.1	....
34.7	110.7	109.8	79.4	30.4	....
9.5	103.3	102.5	77.5	25.0	....
H = 2.5 cm. Medium 27° C.[1]					
9.7	103.4	102.6	63.4	39.2	....
28.3	109.2	108.3	64.3	44.0	0.090
48.7	114.5	113.5	67.0	36.5	62.3°
38.8	111.9	111.0	65.6	45.4	....
24.7	108.2	107.3	64.2	43.1	....
12.8	104.4	103.6	63.6	40.0	....
H = 15 cm. Medium 27° C.[1]					
9.8	103.4	102.6	34.3	68.3	....
25.3	108.3	107.4	35.3	72.1	0.044
46.8	114.0	113.0	36.3	76.7	34.0°
62.7	117.7	116.6	36.7	79.9	....
52.6	115.4	114.4	36.2	78.2	....
34.0	110.6	109.7	35.5	74.2	....
15.8	105.4	104.6	35.4	69.2	....
H = 31 cm. Medium 27.5° C.[1]					
16.2	105.5	104.7	27.0	77.7	0.056
26.1	108.5	107.6	27.7	79.9	26.0°
45.2	113.6	112.6	28.5	84.1	....
54.9	115.9	114.9	28.5	86.4	....
34.5	110.7	109.8	28.1	81.7	....
10.0	103.4	102.6	26.7	75.9	....
B. H = 0.7 cm. Medium 25° C.[2]					
9.7	103.4	102.6	80.1	22.5	0.070
32.0	110.2	109.3	81.3	28.0	79.4°
51.2	115.1	114.1	83.2	30.9	....
43.0	113.1	112.1	82.7	29.4	....
20.8	106.8	106.0	81.1	24.9	....

[1] Hot junction in steam box.

[2] Hot junction just below nozzle.



Curves *H* showing the increase of temperature (ordinates) for the different pressures (abscissas in cm. of Hg) actuating the steam jet at different heights (*H* in cm.) above the nozzle.
Curves *P* showing the limiting value ($P=0$) of the temperature (ordinates), at different heights above the nozzle (abscissas in cm.) when the actuating pressure approaches zero.

TABLE 9.—*Change of temperature at a given axial point of the jet, with the actuating steam pressure. Barometer 76 cm.*—Continued.

$H=2.9$ cm. Medium 26° C.[1]

P	T'	T	t	$T-t$	$\frac{dt}{dp}$, t_0
10.5	103.6	102.8	53.7	69.1	0.110
31.7	110.0	109.1	56.8	52.3	52.9°
73.3	120.0	118.8	60.9	57.9	....
58.0	116.6	115.5	59.1	56.4	....
40.4	112.4	111.5	57.5	54.0	....
19.6	106.5	105.7	65.4	40.3	....

$H=5.2$ cm. Medium 27° C.[1]

9.0	103.1	102.3	46.4	55.9	0.093
33.2	110.4	109.5	48.6	60.9	45.7°
44.9	113.5	102.5	50.0	52.5	....
21.6	107.2	106.4	47.9	58.5	....
10.3	103.5	102.7	46.9	55.8	....
52.2	115.4	114.4	49.6	64.8	....

[1] Hot junction just below nozzle.

C. SUMMARY: $P=0$.

$H=0.9$ cm.	$t_0=76.8°$	$\frac{dt}{dp}=0.060$	$H=0.7$ cm.	$t_0=79.4°$	$\frac{dt}{dp}=0.070$
$=2.5$	$=62.3°$	.090	$=2.9$	52.9°	.110
$=.15$	$=34.0°$	.044	$=5.2$	45.7°	.093
$=.31$	$=26.0°$	.056			

Taking these results as a whole (Pl. I), the linear relation of the temperature at any given point of the jet and the actuating steam pressure can no longer be doubted. The groups A and B are distinct. This is best seen in the summary C, Table 9. If the limiting temperature (t_0 for $P=0$) at divers heights in the jet be constructed, the two loci "$P=0$" of the chart are obtained. They are alike in character (section 59). Their difference is such as to imply a colder medium in the case B, probably much colder than the data actually observed. (Section 60, end.)

Moreover, the slopes of the lines A are as a rule smaller than those of B; but here, as in the case of the variation of the slope with the position H of the point, the evidence is not certain. The distortion is largely due to the fact that an axial position of the junction was not uniformly obtained, and for this reason the changes of slope are irregular. A mean value for each set A and B will best represent the conditions, aside from H.

58. *Data. Low-temperature environment.*—Table 10 contains results for a steam jet discharging into cold air. At 15° C. the appearance as compared with the foregoing is quite striking, for the jet has now fully doubled its former dimensions,[1] being about a meter long and 10 cm. in diameter. This indicates the importance of a more accurately defined and constant air temperature than the present paper evidences, and is in keeping with my earlier results[1] on the contours of the opaque field in Chapter III. Because of these swollen dimensions of the jet, the axial adjustment of the thermocouple is more easily made (probably); at least the present observations are the smoothest of the whole series A few alterations were made at the manometer, a wider tube and a glass scale being inserted.

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[1] Barus: Am. Meteo. Jour., x, p. 11, 1893.

The two parts *A* and *B* of the table differ, as explained in the foot notes, and the summary, C, contains the derived results.

Table 10.—*Change of temperature at a given axial point with the actuating steam pressure. Barometer 76 cm.*

A. $H=1.1$ cm. **Medium 20°; Galv. 12° C.** *a*

P.	T'.	*T.*	*t.*	100 − *t.*	*T* − *t.*	$\frac{dt}{dp}$, t_0
Cm. Hg.	°*C.*	°*C.*				
9.2	103.2	102.4	71.6	....	30.8	0.120
34.6	110.7	100.8	74.3	....	35.5	70.4°
49.1	114.5	113.5	76.3	....	37.2	....
56.2	116.2	115.1	77.4	....	37.7	....

B. $H=0.4$ cm. **Medium 17.5° C.** $T'=100.2°$ **(constant).** *b*

13.1	104.5	103.7	82.9	....	20.8	0.124
26.9	108.6	107.7	84.6	....	23.1	81.3°
42.0	112.7	111.7	86.9	....	24.8	....

$H=0.8$ cm. **Medium 17.0° C.** *b*

15.7	105.4	104.6	80.8	....	23.8	0.127
31.5	110.0	109.1	82.7	....	26.4	78.7°
41.8	112.7	111.7	84.1	....	27.6	....

$H=2.5$ cm. **Medium 17.6° C.** *b*

11.6	104.0	103.2	60.1	....	43.1	0.120
33.0	110.4	109.5	62.7	....	46.8	58.6°
44.3	113.4	112.4	64.0	....	48.4	....

$H=4.6$ cm. **Medium 18.0°.** *b*

8.2	102.8	102.0	46.2	....	55.8	0.204
26.7	108.6	107.7	50.0	....	57.7	44.4°
39.4	112.2	111.3	52.5	....	58.8	....

a **Hot junction in steam box.** *b* **Hot junction in boiling-point apparatus.**

C. Summary, *P* 0. Medium 17°–18.0°.

$H=0.4$ cm.	$t_0=81.3°$	$\frac{dt}{dp}=0.124$
0.8	78.7	.127
(1.1)	(70.4)	(.120)
2.5	58.6	.120
4.6	44.4	.204

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[1] Aitken's observations on the effect of cold on jets are given in Proc. Roy. Soc., LI, p. 414, 1892.

The chart Pl. II accompanies this table, the height H of the point of observation being, as usual, marked on the lines. The data of the summary ($P=0$) are inscribed on the right side of the chart, and they are consistent throughout, showing a curve of the kind already met within the earlier results, but with a clear tendency to become tangent to a lower asymptote.

The marked feature of these results is the large values of the slopes, thus bearing out the inferences made in case of the preceding tables, where the slope was found to increase when the temperature of the medium decreased. (Section 57.)

59. *Longitudinal distribution of temperature.*—Having obtained a satisfactory expression for the variation of temperature at any axial point of the steam jet when the actuating pressure varies, the next results to be sought for are the distributions along the axis from point to point, as well as the radial distribution within any right section. Some notion of the former of these cases has already been obtained from the data of Table 8 to 10 or Plates I and II; for by selecting all the values of the jet temperature which correspond to a given pressure (for instance, $P = 0$), the dependence of the stated temperature of the height H of the point above the nozzle appears. This method is not apt to give the best results, however, owing to the fact that the temperature of the medium and other secondary conditions are apt to vary during the long intervals of observation.

I have therefore made special observations on the longitudinal distribution of temperature by using the jet with attached slide shown in fig. 24, and the results are given in Table 11, where H denotes the height above the nozzle at which the temperature is t at the constant pressure P.

The best results obtained are those under A, where the pressure is maintained at $P = 50$ cm. A full set of measurements was also made for $P = 25$, nearly; but unfortunately the medium of air was colder. A fragmentary series was made for $P = 75$ cm., as the available steam did not enable me to complete the work. The medium here was at a higher temperature (datum lost) than in either of the other series.

The data of Table 11 are inscribed in the chart, Pl. I (curves P), and the probable nature of the contours is shown clearly enough. Owing to the difference of air temperature, however, the curves are not at once comparable. Accepting the vertical distributions given by any one of them, the changes due to pressures are found from Tables 8 to 10, above, as will presently be shown (sections 64, 65).

TABLE 11.—*Axial distribution of temperature in the steam jet.*

A. Galv., 12°; medium, 17.5°-18.0°; barometer, 76 cm. $P = 50$ cm.[1]

H.	T'.[1]	T.	t.	$T-t$.
Cm.	°C.	°C.	°C.	°C.
0.5	114.7	113.7	83.1	30.6
1.1	114.7	113.7	76.4	37.3
1.3	114.6	113.6	72.6	41.0
3.2	114.7	113.7	57.0	56.7
5.3	114.8	113.8	48.5	65.3
8.1	114.7	113.7	40.7	73.0
12.0	114.7	113.7	34.2	79.5
17.1	114.8	113.7	28.9	84.8
23.9	114.9	113.8	24.6	89.2
35.0	114.8	113.7	20.5	93.2

B. Medium, 16°-18°. $P = 24.5$ cm.[2]

0.9	108.1	107.2	77.2	30.0
2.0	108.2	107.3	65.4	41.9
3.4	108.1	107.2	57.5	49.7
3.9	108.1	107.2	51.6	55.6
5.2	108.0	107.1	46.6	60.5
7.0	108.0	107.1	40.6	66.5
11.8	108.2	107.3	32.5	74.8
15.0	108.1	107.2	28.7	78.5
20.5	108.2	107.3	24.1	83.2
27.5	108.2	107.3	20.5	86.8

C. Medium? $P = 75$ cm.[1]

1.2	120.6	119.4	78.3	41.1
3.3	120.5	119.3	64.0	55.3
5.8	120.5	119.3	53.6	65.7
9.6	[3]119.6	118.5	44.7	73.8

[1] Hot junction in steam box.
[2] Hot junction in the nozzle.
[3] Steam low.

60. *Radial distribution.*—The expansion of the visible envelope of the jet when the temperature of the medium is decreased has already been alluded to. (Section 58.) Inasmuch as the bulk or unclear part of the jet is a region of condensation, and the mantel or margin a region of evaporation (for the water globules here disappear by solution and evaporation), the radial distribution of temperature is of considerable interest. One might reasonably expect the outer surface of the jet (not too near the nozzle) to be at a temperature below that of the atmosphere.

I have commenced a study of this subject since it does not enter directly into the present work, and a few data are given in Table 12. Pressure P being maintained at 25 cm. of mercury, observations were made about 12 cm. above the nozzle, where the apparent width of the column of steam was about $2R = 4$ cm. The radial position of the thermoelectric junction is given in centimeters under r, so that the first position ($r = 0$) was in the axis, the third in the outer surface of the jet, and the last ($r = 4$) in the circumambient air.

TABLE 12.—*Radial distribution of temperature in the steam jet*

H = 12 cm.; P = 25.0 cm., Hg.; 2 R = 2 × 2 cm.; medium 18° C.[1]

r.	*T.*	*T'.*	*t.*	Remarks.
Cm.				
0	108.2°	107.3°	32.5	Center.
1			26.9	Middle.
2			16.4	Edge.
4			13.1	Air.

[1] Hot junction just below nozzle.

These results are also given on Pl. II, in the curve *c a*, of which the ordinates are temperatures and the abscissas distances in centimeters (*r*) of the point in question from the axis of the jet, or from the center of the right section, 12 cm. above the nozzle. Since the medium was at a temperature of nominally 18°, the low temperatures (16.4°, 13.1°) occurring near the edge of the jet are striking features.

Owing to the apparently anomalous way in which the air temperature enters the foregoing results, I carefully repeated the work by surveying across the jet, keeping the junction on a horizontal line (high H above the nozzle) passing through the axis of the jet. In the next table, R is the position of the junction relative to this arbitrary horizontal scale, and t the corresponding temperature. P and T denote pressure and temperature in the steam box, as usual.

TABLE 13.—*Radial distribution of temperature in the steam jet.*

R.	*t.*	*R.*	*t.*	*R.*	*t.*
H = 25 cm. P = 30 cm. T = 109.5°.					
Cm.	°C.	*Cm.*	°C.	*Cm.*	°C.
39.5	17.0	31.0	27.0	24.0	17.6
37.0	17.4	29.5	29.6	22.0	16.6
34.0	19.4	28.0	28.6		
32.5	22.5	26.0	23.3		
H = 25 cm. P = 50 cm. T = 114.7°.					
40	18.3	30	28.3	22	17.3
37	18.6	28	30.6	20	17.2
34	19.4	26	26.5	40	17.3
32	24.0	24	19.5		
H = 13 cm. P = 50 cm. T = 114.7°.					
37.5	18.7	27.5	34.0	32.0	19.5
34.5	19.0	26.0	20.4	30.0	32.9
32.5	19.5	24.0	17.3	28.5	37.8
31.0	28.6	22.0	17.3	27.0	29.6
30.5	29.1	38.0	17.9	25.0	17.7
29.0	37.7	34.0	18.3		

The results are graphically shown in the chart, fig. 26, where temperatures are the ordinates and points along a diameter the abscissas. The whole temperature variation occurs within the visible width of the jet. Moreover, the maxima are sharp, so that in a general way one can put the temperature at any point along the horizontal radius as a mean between the air temperature and the corresponding temperature at the center of the right section (axis). None of the curves are quite symmetrical, but this is due to incidental causes, for the jet was not quite vertical and the conveyance pipes lay largely to the right or hotter part of the jet.

The chief point gained in this work is the fact brought out that the jet temperatures fall off radially into the air temperature, and that they do not pass through a minimum, as was supposable. Further and direct observations (which I will omit) showed the cause of relatively cold temperatures around the jet to be referable to an unequally heated room, for the air rushing up around the jet came largely from the floor and was sensibly colder than the mean room temperature.

61. ***Fall of temperature in the connecting pipe.***—The tube connecting the nozzle with the steam box was made as short as the other needful adjustments would permit. But a piece of rubber hose 40 cm. long (including the brass end pieces), securely wrapped with cloth and non-conducting felting, was essential. The result, nevertheless, is a difference of temperature between the steam box and the inner face of the nozzle, as shown in Table 14. Here one of the thermoelectric junctions was placed in the steam box as usual, and the other in the jet pipe just below the nozzle.

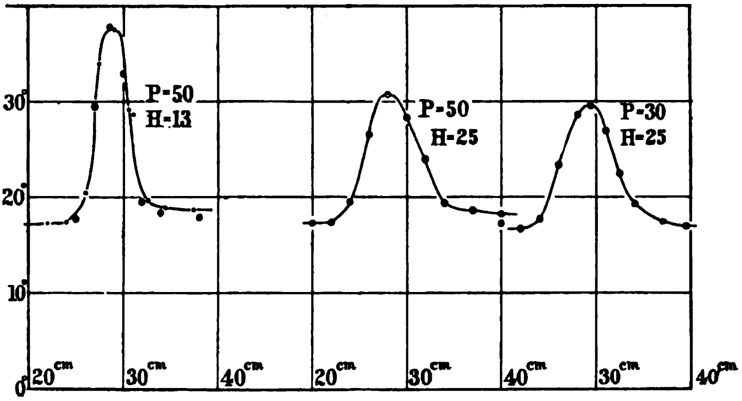


FIG. 26.—Radial distribution of temperature.

The fall of temperature is not negligible, but it is not seriously large. The interesting feature about it is, that the difference of temperature $(T-t)$ is clearly a linear function of the actuating pressure,

$$(T-t)=0.70^\circ+0.0063\,P,$$

as is shown by the curve *mn* of Pl. II. Thus, in a smaller scale, the inferences and observations of sections 57, 58 (curve *II*) are reproduced, even in the case of restricted expansion in pipes. The curve *mn* is such as to imply a definite difference of temperature (0.7 °C.), even when the actuating pressure approaches zero, and this difference increases with pressure at the rate 0.0063 °C. per centimeter of mercury indefinitely.

TABLE 14.—*Distribution within the influx pipe. Jet 1 meter long, 10 cm. wide; medium 16°.*

[Junctions respectively in the nozzle and in the steam box.]

P.	T.	t.	$T-t$.	$\frac{d(T-t)}{dP}$; $(T-t)_0$.
6.0	102.2	101.5	0.72	
22.5	107.4	106.5	.86	0.0063
37.6	111.6	110.7	.92	0.70
46.2	113.8	112.8	1.01	

With these very definite results in hand it is easy to compute either the temperature or the pressure of the steam, just before leaving the nozzle, from the pressures observed in the steam box. In view of the low room temperature (16°) the present test is a severe case.

INFERENCES.

62. *Structure of the jet*—Before proceeding to a discussion of the above data it is in place to insert a few words on the appearance of the jet near the nozzle. This is found to be strikingly like the Bunsen flame, where a mantel of combustion surrounds a blue cone of unburnt gas. So in the steam jet the axis immediately above the nozzle is surrounded by a colorless spindle-shaped region, consisting largely of uncondensed vapor, which in its turn is enveloped by the opaque mantle of condensation. The latter does not reach downward quite to the plane of the nozzle, but terminates in a ring parallel to the nozzle and at a distance about it decreasing when the actuating steam pressure increases or the temperature of the medium decreases. Thus, at 18° C., the following values of the heights (h) of the condensation limit were found at different steam pressures (p)

$$h = 0.8 \quad 1.1 \quad 1.3 \quad 1.8 \quad 1.5 \quad 2.0 \quad 1.2 \quad 0.9 \text{ cm.}$$
$$p = 44 \quad 37 \quad 26 \quad 13 \quad 3 \quad 18 \quad 29 \quad 36 \text{ cm.,}$$

showing some irregularities due to the difficulty of observing, but bearing out the statement made clearly enough. The condensation limit at 18° falls about 0.04 cm. per mercury cm. of increase of the actuating steam pressure.

Now, just as in the case of the Bunsen flame, the contours are a locus indicating the speed of the chemical reaction, so in the case of the steam jet the position of the ring in question indicates the speed of condensation. From this an important consequence may be drawn. It is obvious that the velocity with which the steam escapes from the nozzle increases nearly at the same rate as the actuating steam pressure. It is probable that this velocity falls off rapidly from the nozzle outward. Moreover the position of the limit of condensation indicates the height above the nozzle at which the velocity of the escaping steam outward is just equal to the speed of condensation moving from without inward. Inasmuch, therefore, as the limit of condensation moves toward the nozzle when the pressure increases, the speed of condensation must increase in marked degree with the actuating pressure. This is equivalent to saying that the degree of supersaturation near the nozzle increases remarkably when the actuating steam pressure increases—an important inference which will be utilized in the course of the following work.

Anticipating some of the following results, the above data may be thus interpreted:

The effect of the above variations of pressure on the temperature at a given point near the nozzle would be

4.4° 3.7° 2.6° 1.3° 0.3° 1.8° 2.9° 3.6°

respectively, and the effect of the shifting in the position of the limit of condensation would be

11° 9° 7° 1° 4° 0° 9° 11°,

indicating the preponderating influence in the latter case.

63. *Character of the axial distribution.*—At this stage of progress it is necessary to determine the law of longitudinal distribution of the temperature of the steam jet as accurately as possible. Looking at the curves of the above plates, particularly Pl. II, the possibility of an hyperbolic equation suggests itself by reason of its simplicity. Thus the equation

$$t-B=\frac{A}{1+kh}$$

where t is the temperature at a distance h above the nozzle and A, B, and k are constants, has the following properties: At the surface of the nozzle, $h=0$ and $t=A+B$. At a point indefinitely high above the jet, $h=\infty$ and $t=+B$. Thus, if the assumptions be made that indefinitely near the nozzle and on the outside the temperature is 100°, $A+B=100$, the value of B should be the air temperature of the room; but it is quite difficult to know what the efficient air temperature actually is in a heated or steam-charged room. A trial suggests $B=14°$ whereas the measured room temperature below the jet was about 17°. If k be then computed for $A=86$ and $B=14$ from Table 11 (A), as

$$k=\frac{A+B-t}{h(t-B)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

the values fluctuate around $k=0.35$. Compared with the observed values of t (Table 11 A), the computed values show discrepancies as large as 5° where the observational errors lie certainly within 1°. The equation is therefore to be dismissed.

Aside from this a direct test can be made on the insufficiency of equation (1) since $\frac{1}{t-B}$ and h if plotted in terms of each other must give a straight line. As the approximate value of B is given, successive trial values of $t-B$ may be compared. Thus, the shortcomings of (1) become manifest.

64. *Exponential constants.*—In general it is scarcely probable that a simple equation would express the complicated phenomenon of the jet. I have therefore worked backward from the data of Table 11, as follows: The observations of part A are so made that the corresponding finite increments of temperature Δt and of height ΔH can be easily compared, and the points of the curve are close enough together that $\frac{\Delta t}{\Delta H}$ will be nearly the same as the differential coefficient $\frac{dt}{dh}$, where dt is the infinitesimal increment of temperature corresponding to the increment of height dh, at the axial point h centimeters above the nozzle. Instead of $\frac{dt}{dh}$ it is practically more convenient to take $\frac{dh}{dt}$, because these data lie within more convenient limits. If $\frac{dh}{dt}$ be compared with t graphically, the locus is strongly curved and does not show any marked simplification over the integral locus for h and t. If, however, $\frac{dh}{dt}$ and h be compared, the locus is much flatter than before, so that a simple exponential form can reach it. Put therefore

$$-\frac{dh}{dt}=10^{Bh}-1 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

where B is a constant, or

$$\log\left(1-\frac{dh}{dt}\right)=Bh \quad . \; . \; . \; . \; . \; . \; . \; . \quad (2')$$

remembering that $\frac{dh}{dt}$ is negative throughout. Plotting the data of (2) graphically, viz, $\frac{dh}{dt}$ as a function of h, it is seen that the linear character is actually sustained. B may therefore be computed, and the results are given in Table 15, h being the height of the middle of the increment.

TABLE 15.—*Comparison of* $\frac{dh}{dt}$ *and* h *of Table 11, A, assuming that* $\log\left(1-\frac{dh}{dt}\right)=Bh$.

h	$-\frac{dh}{dt}$	B	h	$\frac{dh}{dt}$	B
0.8	0.000		10.0	0.600	0.0204
1.2	.053	.0187	14.5	0.960	.202
2.2	.125	.232	20.5	1.58	.201
4.2	.250	.231	29.5	2·70	.193
6.7	.360	.199	Mean.	$B=$	0.020

If the points near the nozzle where observation is difficult and uncertain be overlooked, the group of values thus obtained is good enough to suggest further inquiry. Equation (2) is virtually a differential equation of the second order, or at least can be easily put

$$\frac{d^2h}{dt^2} = B\,(\ln 10)\,\frac{dh}{dt}\left(\frac{dh}{dt}-1\right),$$

which on integration leads to

$$10^{-Bh} = 1 - 10^{-B(t+A)}$$

or to

$$B\,(t + A) = -\log\,(1 - 10^{-Bh}) \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and thus the differential equation.

$$\frac{dt}{dh} = 1 - 10^{B(t+A)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

corresponds to (2).

If in (3), $h=\infty$, then $t = -A$; and thus $-A$ is the temperature of the medium into which the steam is discharged and is approximately known from observation. If $h=0$, $t=\infty$, indicating that the temperatures near the nozzle must be enormously high. Whether or not this is a real insufficiency of equation (3) can not be easily seen, for the temperatures near the nozzle do not lend themselves to accurate observation. The remedy, however, is not far to seek; for if, instead of 2′ the equation

$$\log\left(1-\frac{dh}{dt}\right) = -\log C + Bh \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

be evaluated, the integral will be

$$B\,(t+A) = -\log\,(1 - C\,10^{-Bh}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

in which if $h=\infty$, $t=-A$ as before; and if $h=0$, $t=-A-\frac{1}{B}\log(1-C)$ and therefore remains finite, remembering that both A and $\log(1-C)$ are inherently negative. It will presently be seen that the agreement with observational values thus obtained is very good.

The convenience of equation (6) is manifest, since both B and C are obtained graphically, and it is merely necessary to compute $-A$, the quantity which symbolizes the efficient atmospheric temperature. The following table shows a satisfactory set of values:

TABLE 16.—*Values of* $-A$, *in the equation* $B\,(t+A) = \log\,(1-C\,10^{-Bh})$, *when* $B = 0.019$, $C = 0.977$.

h	t observed.	$t+A$ computed.	$-A$
Cm.	°*C.*	°*C.*	°*C.*
0.5	83.1	71.38	(11.7)
1.1	76.4	61.17	15.2
1.3	72.6	58.61	14.0
3.2	57.0	43.26	13.7
5.3	48.5	34.08	14.4
8.1	40.7	26.44	14.3
12.0	34.2	19.72	14.5
17.1	28.9	14.20	14.7
23.9	24.6	9.60	15.0
35.0	20.5	5.43	15.1
	Mean.	A -	14.54

In this table the values of $-A$ for $h=1.1$, 23.9, 35.0 cm. are above 15°, but these observations were made in the afternoon, when the room temperature was about 1° higher than in the morning. The remaining observations show a gradual increase of $-A$, due to the same cause that the room temperature was gradually rising, even during the morning. The value of $-A$ for $h=0.5$ is too low, also easily explained because of the difficulties of measuring temperature near the nozzle where the jet is narrow. Hence if

$$t=-A-\frac{1}{B}\log(1-C\,10^{-Bh})$$

the observations are well reproduced when the constants are

$$-A=14.66^\circ;\ B=0.019;\ C=0.977,$$

whence

$$h=\infty;\ t_\infty=-A=14.7^\circ$$

$$h=0;\ t_0=-\frac{1}{B}\log(1-C)-A=100.8^\circ$$

Both t_0 and t_∞ are virtually predications of equation (6), and the fact that the first lies so near the air temperature and the second so near the normal boiling point of water are the important features of the equation taken

In the same way the other series of data B and C of Table 11 might be discussed. But it is expedient to derive the corresponding curves from the pressure variations found in the earlier tables, and thus to obviate the change of the arbitrary variable for the temperature of the medium.

65. *Graphic digest.*—Utilizing the constants computed in the earlier paragraph, I have constructed Table 17, in which, together with other data, a full account of the change of temperature, t_{50}, along the axis from the nozzle to a height h, of about a meter above this point, is given. These results are graphically shown in the chart, Pl. III, where (as usual) height in centimeters above the nozzle is the abscissa and temperature in °C the ordinate. The observations are also inscribed for the actuating steam pressure $P=50$ cm. of mercury, being Table 11, part A, where the temperature just inside of the nozzle is $T=114^\circ$. Little circles drawn around the points distinguish these observations from other data to be presently explained. The curve for t_{50} is drawn out in full. All the observations coincide with it, excepting the last two perhaps. But these were made when the air temperature was warmer, and their position is therefore in accord with this fact. The enormous fall of temperature within a few millimeters on either side of the nozzle is well shown near the origin of the curve.

TABLE 17.—*Axial distribution of temperature in the steam jet.*

$$t=-A-\frac{1}{B}\log(1-C10^{-Bh});\ P=50\text{ cm.}$$

$$-A=14.54^\circ;\ B=0.019;\ C=0.977;\ T=114^\circ.$$

$$B'=0.0204;\ B''=0.0177.$$

h	t_{50}	t'	t''
Cm.	°*C.*	°*C.*	°*C.*
0.0	100.8	94.80	106.80
1.0	77.0	71.84	82.61
2.0	66.2	61.54	71.17
3.0	59.0	54.76	63.60
4.0	53.8	49.84	58.03
5.0	49.7	46.04	53.65
6.0	46.4	42.96	50.08
8.0	41.2	38.21	44.53
10.0	37.3	34.62	40.31
12.0	34.3	....	....
15.0	30.7	28.60	33.07
18.0	28.0	....	....
20.0	26.5	24.79	28.44
25.0	23.6	....	....
30.0	21.5	20.34	22.87
35.0	20.0	....	....

h	t''	t'	t''
40.0	18.8	17.97	19.76
50.0	17.2	16.63	17.88
60.0	16.2	....	....
80.0	15.2	....	....
100.0	14.8	....	14.95
	14.54	14.54	14.54

SUMMARY.

$h=$	$\frac{dt}{dp}=$
0 cm.	0.120
10	.057
20	.037
30	.025
40	.018
50	.013

66. *Effect of steam pressure.*—In Table 8 the values of $\frac{dt}{dp}$ lie between 0.09 and 0.07; but the temperature of the medium is not given. In Table 9 these values lie between 0.06 and 0.11. A relation to the height (H) above the nozzle can not be made out. The medium is at 26° to 27° C. In Table 10, $\frac{dt}{dp}$ is usually 0.12 in value, though there is a jump in the last of the values to 0.20. The medium is usually 17° to 18°.

All that can be inferred from this is an increase of the pressure coefficient, when the air temperature is colder, and it may be roughly rated as a decrease of 0.0025 for $\frac{dt}{dp}$ for each degree of increase of the temperature of the medium. Throughout this paper the temperature of the medium does not enter sharply, because I worked in an unequally heated room. The heat radiated by the jet introduces a discrepancy.

Suppose, temporarily, that $\frac{dt}{dp}=0.12$, since the media in tables 10 and 11 were nominally at the same temperature, and let the variation of $\frac{dt}{dp}$ with the height H of the point above the nozzle be overlooked.

Then the temperature at every point of the axis of the jet is 0.12° colder for each centimeter of decrease of pressure. The effect of a given increment of pressure is therefore to shift the position of the curve (t and h), as a whole, in a vertical direction. This result is the closest approach to the actual state of the case which my observations enable me to make. But the solution can not be correct, since it involves thermal shifting of the asymptote ($h = \infty$), and the results for radial distribution of temperature (section 60) show clearly enough that the curve must terminate on all sides in the temperature of the air medium.

I have endeavored to get around these difficulties in the following way. Suppose, as before, that initially $\frac{dt}{dp}=0.12$, but that it is a variable quantity, falling off gradually to zero as the height above the nozzle increases. There is some evidence of this in Table 9, but apart from data the result is necessary. Solving the above equation for $h=0$

$$t_0=-A-\frac{1}{B}\log(1-C)$$

where t_0 is the temperature just outside of the nozzle, and A, B, and C are constant, $-A$ the temperature of the medium (14.54°) retains its former value, so that the effect of pressure in changing t_0 can only be represented by changes of B and of C. The effect on t produced by changes of B and C may be found by differentiation; but the results are involved and it is more satisfactory to make an actual computation.

Since the curve of the chart corresponds to $P=50$ cm. of mercury, let the curves t' for $P=0$ and t'' for $P=100$ be computed. The initial effect of pressure is therefore $-6°$ and $+6°$, respectively, so that

$$t'=94.8°,\ t_{50}=100.8°,\ t''=106.8°,$$

and if at first C be considered constant (0.977 as above), and B only variable, the results $B'=0.204$ and $B''=0.0177$ are obtained.

The data so computed are also given in Table 17. They are distinguished in the chart by the aid of dashes pointing, respectively, to the left upward and to the right upward.

The first result obtained in this is way important. Remembering that t' to t_{50} and t_{50} to t'' correspond to equal steps of pressure (50 cm. of mercury each), and that $P''-P'=100$ cm. is much above the interval of observation, the occurrence of t_{50} as a mean between t' and t'' shows the above linear variations of temperature and pressure (sections 57–58) to be reproduced. The discrepancy is rarely above 0.1°, which would easily escape observation. Thus far the postulate of B variable with pressure accords with the observations.

If, however, the data for $\frac{dt}{dp}$ be computed (see end of Table 17), they decrease with h rather more rapidly than the observations warrant. I have shown this in the chart near the bottom, where the observations of Table 9 are shown by crosses, these being the only ones available.

TABLE 18.—*Axial distribution of temperature in the steam jet.*

$$t+A=-\frac{1}{B}(1-C\,10^{-Bh}).$$

$$C=0.977;\ C''=0.982;\ C'=0.970.$$

$$B=0.019;\ A=14.54.$$

h	t_{50}	t''	t'	h	t_{50}	t''	t'
Cm.	°C.	°C.	°C.	Cm.	°C.	°C.	°C.
0	100.8	106.80	94.80	10	37.3	37.52	37.03
1	77.0	78.74	74.75	15	30.7	30.82	30.54
2	66.2	66.99	64.82	20	26.5	26.58	26.38
3	59.0	59.71	58.04	30	21.5	21.57	21.45
4	53.8	54.32	53.04	40	18.8	18.82	18.77
5	49.7	50.16	49.13	50	17.2	17.22	17.19
6	46.4	46.72	45.88	100	14.8	14.83	14.83
8	41.2	41.46	40.84	∞	14.5	14.54	14.54

Again, let B in equation be constant and C the variable. Then the values

$$C'=0.970,\ C=0.977,\ C''=0.982$$

are obtained as before, from which the data of Table 18 are computed. They are distinguished in the chart by points with dashes to the right and left downward. It is seen that with the exception of points near the origin, the curves t' and t'' run rapidly into t_{50}, so that even as near the nozzle as $h=1$ cm., they could not be easily distinguished with certainty.

Hence it must be possible to vary B and C simultaneously in such a way as to produce contrary effects on t, and a slower decrease of $\frac{dt}{dp}$ than was obtained in Table 17 will then result. I will not, however, carry this out, since the data necessary to test the results are not in hand, but will conclude with the following general remark:

67. *Conclusion.*—All the observations go to show that the temperature of the jet changes with the actuating steam pressure quite up to the plane of the nozzle. In the latter case when $P=0$, the temperature should be $t_0=100°$ (supposing the barometer normal). If, therefore, the equation

$$t+A=-\frac{1}{B}\log(1-C\,10^{-Bh})$$

be taken, whence

$$t_0+A=-\frac{1}{B}\log(1-C),$$

and if the effect of the medium be left out of consideration (supposing its temperature constant), then the axial distribution of temperature for $P=0$ should commence with $t=100°$ at $h=0$, and all other curves of the family lie bodily above this in proportion as P is greater. In other words, if $\mu=\frac{dt}{dp}$,

$$100+\mu P+A=-\frac{1}{B}\log(1-C)$$

and the problem then consists in so determining B and C that the observations are reproduced. The values of the present paper may be regarded as approximations.

I have proceeded in the above purely experimental way because the theoretical side of the problem involves formidable difficulties. So far as I have gone the phenomena seems to lend itself to a determinate experimental solution.

CHAPTER V.

DISTRIBUTION OF TEMPERATURE IN THE COLOR TUBE.

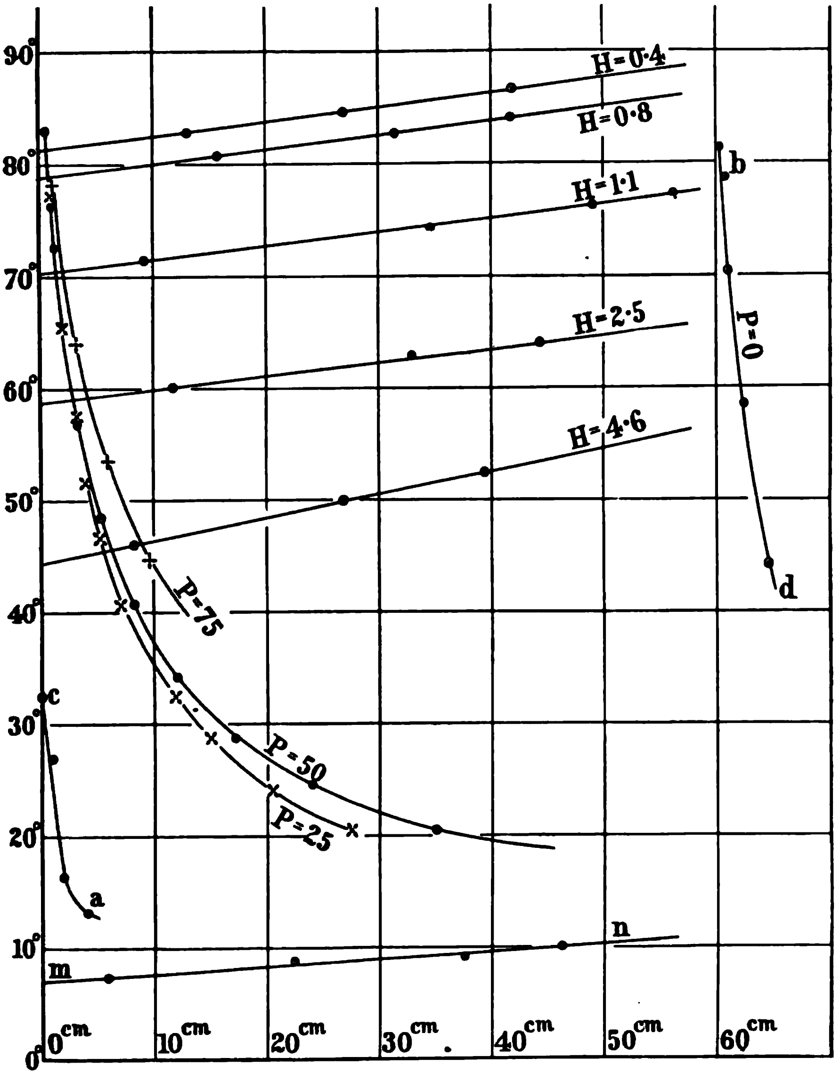
68. *Points of view.*—In the preceding chapter the effect of the temperature of the medium on the thermal topography of the steam jet was merely stated inferentially. I shall in the present chapter endeavor to obtain data of a more specific character. Moreover, the effect of the tube on the temperatures of the inclosed jet is to be compared with the case of the free jet, both in regard to the axial distribution of temperature as well as to its variation at any point with pressure. Results so obtained will apply more directly to the colored cloudy condensation within the tube.

69. *Temperature. Axial distribution.*—The first point at issue is the change of temperature along the axis of the color tube. It is clear at once that inasmuch as the opportunities of radiation and continued mixture are largely cut off, the change of temperature must be more gradual than was observed for the free jet.

To make these measurements, five holes were drilled into the color tube at suitable distances apart, and each hole provided with a short tubulure so that it could be closed with a cork. When observations were to be made at any point the cork was withdrawn and the junction of the thermocouple (sections 52, 53) there inserted. To obtain the present data it was therefore merely necessary to move the couple from hole to hole upward. As a rule, there was little difficulty in securing an axial adjustment of the couple, except near the nozzle, where the narrowness of the jet introduced discrepancies of the kind already sketched above. (Sections 55, 56.)

The hot junction was kept at the boiling point of water by the aid of an apparatus for continuous ebullition. Computations were made as before. (Section 54 et seq.)

Table 19 shows the results of these measurements, H denoting the height of the junction above the nozzle of the jet and t the temperature there observed. The pressure (P) actuating the jet was kept at about 30 cm. of mercury, and fluctuated within about 1 cm. The temperature (θ) of the inflowing air had the mean value of 17° C. though a fluctuation within 1° C. was unavoidable. It will presently be seen that the discrepancies introduced by both these irregularities are small. A source of greater annoyance is the hot water, which condenses in the jet and is squirted out against the junction from time to time. Observations must therefore be made when the jet is flowing smoothly. In the table, values of H near the nozzle are put in parenthesis because of the uncertainty of this measurement.



Curves *H* showing the increase of temperature (ordinates) for the different pressures (abscissas, cm. of Hg) actuating the steam jet, at different heights (*H* in cm.) above the nozzle.
Curves *P* showing the values of the temperature (ordinates) at different heights above the nozzle (abscissas in cm.) when the actuating steam pressure *P* has a fixed value.
Curve *c a r* showing the radial distribution of temperature (ordinates) in terms of the radius (*r* in cm.) of a right section, where the visible width of the section is $2r = 4^{cm}$.
Curve *m n* showing the difference of temperature (ordinates magnified 10 times) between the steam box and the inside of the nozzle, when pressure (abscissas cm. of Hg) varies.

TABLE 19.—*Longitudinal thermal distribution in the color tube.*

$P = 30$ cm. $\theta = 17.1°$ C.

H	t	H	t
Cm.	°C.	*Cm.*	°C.
46	38.2	(1)	82.0
34	39.2	(0.4)	97.0
20	40.5	46.0	39.0
8	44.7		

70. *Digest and chart.*—The values of Table 19 are platted in the chart, Pl. IV, curve *a b*, the temperatures being the ordinates, and the heights above the nozzle the abscissas. To bring out the nature of this curve I have also platted the corresponding data *c d*, obtained in the preceding chapter, for the axial distribution in the free jet. (Section 59.) Thus, so far as the evidence goes, one may assume that within the first 5 cm. of height above the nozzle the two curves coincide. Within this distance the jet retains its filimentary outline. Beyond the stated distance, however, the curves diverge remarkably, the one (*a c b*) for the inclosed jet soon reaching a horizontal asymptote, more than 20° hotter than the other, *a c d*. If the color tube were quite nonconducting, even a sharper inflection would characterize *a c b*, as is proved by the higher temperature of the second of the two points for $H = 46$ cm. in Table 19

From a comparison of the two curves in question the following important deduction may be drawn, remembering that the liquid particles are formed within a few centimeters above the nozzle: (1) Throughout those parts of the inclosed steam jet within which the colored cloudy condensation originates the axial distribution of temperature may be regarded as identical with the corresponding case of a free steam jet, cæt par.; (2) Throughout the remainder of the jet (i. e., in those parts of the color tube in which the water globules are suspended after being formed) the temperature is approximately constant. It is for this very reason that the color tube presents a promising means of studying the gradual growth of water globules, in the manner already stated. (Section 23.)

71. *Effect of pressure.*—If the position of the junction of the thermocouple (H) be fixed and the temperature (θ) of the inflowing air be kept constant, then the effect of the actuating steam pressure (P) on the distribution of temperature (t) within the tube is observable. Again, if for constant values of P and H, θ be varied the effect of air temperature on the thermal distribution (t) will follow.

The data (t) obtained for both of these cases are given in Table 20, those on the left corresponding to constant values of H (height above the nozzle), those on the right to constant values of the temperature θ of the inflowing air. T denotes the temperature of the steam in the steam box, before issuing at the nozzle, and is computed from P. As before, the hot junction of the thermocouple was in the boiling-point apparatus.

TABLE 20.—*Thermal distribution in the color tube, varying with steam pressure and air temperature.*

H = 0.4 cm. *θ* = 19.4°.

P	*T*	*t*	*P*	*T*	*t*
Cm. Hg.	°*C.*	°*C.*	*Cm. Hg.*	°*C.*	°*C.*
24.9	108.2	97.0	38.3	111.7	97.6
50.0	114.7	98.9	13.2	104.4	96.2
74.7	120.3	100.7	5.4	101.8	95.8
60.5	117.2	99.7			

H = 0.4 cm. *P* = 29.9 cm. *T* = 109.5°.

θ	*t*	*θ*	*t*	*θ*	*t*
°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
28.3	96.5	37.0	96.2	24.9	95.5
29.0	96.4	32.5	96.1	22.3	95.5
36.6	96.3	32.0	95.5	37.2	95.8

H = 8 cm. *θ* = 20.8°.

P	*T*	*t*	*P*	*T*	*t*
Cm. Hg.	°*C.*	°*C.*	*Cm. Hg.*	°*C.*	°*C.*
13.6	104.6	41.5	83.0	122.1	42.7
29.3	109.4	41.6	72.0	119.7	42.4
43.0	113.1	41.8	50.3	104.8	42.2
63.7	117.8	42.4			

H = 8 cm. *P* = 30.5 cm. *T* = 109.6°.

θ	*t*	*θ*	*t*	*θ*	*t*
°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
20.8	41.6	29.9	43.4	37.6	46.0
28.3	43.0	37.3	46.4		

H = 20 cm. *θ* = 17.7°.

P	*T*	*t*	*P*	*T*	*t*
Cm. Hg.	°*C.*	°*C.*	*Cm. Hg.*	°*C.*	°*C.*
10.4	103.5	38.1	70.5	119.4	39.4
25.2	108.3	38.7	44.1	113.4	39.2
48.2	114.4	39.5			

H = 20 cm. *P* = 31.8 cm. *T* = 110.1°.

θ	*t*	*θ*	*t*	*θ*	*t*
°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
17.5	38.5	37.3	43.6	22.0	39.2
25.5	39.3	29.7	40.7		

H = 34 cm. *θ* = 16.4°.

P	*T*	*t*	*P*	*T*	*t*
Cm. Hg.	°*C.*	°*C.*	*Cm. Hg.*	°*C.*	°*C.*
20.3	106.7	37.3	59.2	116.8	38.7
47.2	114.1	38.5	31.7	110.1	37.7
76.3	120.6	39.2			

Table 20.—*Thermal distribution in the color tube, varying with steam pressure and air temperature*—Continued.

$H = 34$ cm. $P = 31.2$ cm. $T = 109.8°$.

θ	t	θ	t	θ	t
°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
16.4	37.7	36.7	43.3	22.5	39.4
26.0	39.4	29.1	40.4		

$H = 46$ cm. $\theta = 17°$.

P	T	t	P	T	t
Cm. Hg.	°*C.*	°*C.*	*Cm. Hg.*	°*C.*	°*C.*
15.2	105.2	38.3	78.8	121.2	39.3
29.7	109.5	38.4	63.3	117.8	39.0
48.5	114.4	39.3			

$H = 46$ cm. $P = 33.4$ cm. $T = 110.4°$.

θ	t	θ	t	θ	t
°*C.*	°*C.*	°*C.*	°*C.*	°*C.*	°*C.*
16.7	37.7	36.5	43.6	20.1	38.4
26.8	38.7	29.7	40.4		

Turning first to the values for constant H and θ and variable P, the observations may be inserted in the chart Pl. IV, temperature (t) being laid off vertically and pressure (P) horizontally. The air temperature, θ, and the height, H, above the nozzle, are inscribed on each curve.

As before, sections 57, 58, these curves are straight lines, and they become rapidly crowded together (conformaly with the results of the preceding paragraph) as H increases. The data may easily be summarized by giving the slopes $\frac{dt}{dp}$ for each case, as has been done in Table 21.

Table 21.—*Color tube temperatures, changing with pressure only.*

H	θ	$\frac{dt}{dp}$	H	θ	$\frac{dt}{dp}$
Cm.	°		*Cm.*	°	
0.4	19	0.072	34	16	0.035
8	21	0.020	46	17	0.025
20	18	0.025			

Near the nozzle, therefore, where the temperature of the jet is presumably like the corresponding free jet, the pressure coefficient $\frac{dt}{dp}$ is also of the order of those found in the preceding chapter. Above this the value of the pressure coefficient falls off with great rapidity, so that throughout almost the whole length of the color tube it retains a constant value of about $0.026 = \frac{dt.}{dp.}$

Hence the effect of changes of the actuating steam pressure on the temperature of the tube are of secondary importance, and the reason for this is to be found in the fact that the air current increases nearly proportionally to the steam current.

Incidentally it is interesting to note again the tremendous fall of temperature, $T-t$, observed when $H=0.4$ cm. Thus within the fraction of a centimeter temperatures decrease as much as 20° C. Within 8 cm. above the nozzle they have decreased as much as 80° C., showing the even more marked effect of admixture with air.

72. *Effect of air temperature.*—The second part of Table 20 is now to be discussed in a way similar to the preceding case. Since steam pressure P and height H above the nozzle are now constant, the jet temperature (t) may be laid off vertically and the air temperature θ horizontally. To obviate confusion or crowding of the curves, it is desirable to shift the curves, retaining, however, the same scale as before. This is done in the chart, Pl. IV, where the values of H and P are given for each curve.

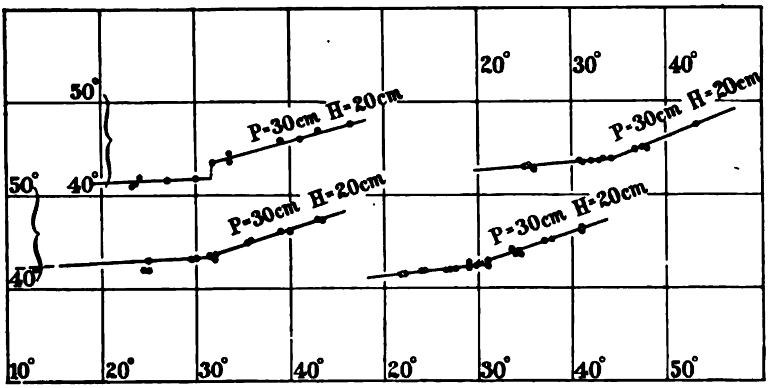


FIG. 27.—Curves showing the temperature in the axis of the color tube.

The first of these curves (for $H=0.4$ cm.) differs in a marked way from the others. It can not be said to possess either curvature or slope, and its position is high (55°) above the other curves. If a slope be conceded, its value must be less than $\frac{dt}{d\theta}=0.02$, proving that for points near the nozzle of the jet the observed cooling is largely (almost wholly) adiabatic. This also agrees with the inferences of the preceding paragraphs.

The remaining curves for $H=8$, 20, etc., are all crowded together in the region of $t=40°$; and, singularly enough, they are well indicated broken lines, with the breaks at nearly the same place ($26°=\theta$). This behavior is at first sight quite puzzling, and, without passing hasty judgment on the matter, I determined to continue the experiments under altered conditions. For this purpose I put a second steam drum into the hot-air pipe, section 30, fig. 14, so that the range of variation of

θ might be sufficiently increased. Moreover, observations were now made both with a thermocouple as well as with a small bulb thermometer. The results are contained in Table 22, the notation being as before. Platting these values in the chart, fig. 27, in the same way as before, the broken lines are obtained in both instances, with the marked exception, however, that the break now occurs at a considerably higher temperature, somewhere between θ=30°–33°. These observations gave me a clue as to the cause of the curious behavior obtained, for the rate at which the air is supplied by the influx pipes, even if they are all of the same diameter, will depend materially on the length and the elbows in these pipes (cæt par). Now the hot-air pipes are not only larger but more crooked than the cold-air pipe. Hence there can be no doubt that less air is supplied when the passage takes place mainly through the hot pipes than when it flows mainly through the cold pipes. It follows that as θ is greater, the amount of air supplied, and therefore its cooling influence, is proportionately less. There will, therefore, be a different rate of heating before and after the cold-air pipe is shut off. This is what the curves (P, H, chart) actually show, and the break changes with the obstructions in the hot-air pipe.

TABLE 22.—*Thermal distribution in the color tube varying with air temperature.*

H=20 cm.; P=30 cm. Hg.

θ	t^1	θ	t^1	θ	t^1	θ	t^2
° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
23.2	41.0	25.0	43.0	25.0	43.0	21.8	41.5
23.5	41.4	23.0	43.0	25.0	43.0	21.9	41.5
27.0	41.6	30.7	43.5	29.5	43.1	26.5	42.0
30.0	41.8	32.0	43.6	30.0	43.3	27.0	42.0
33.5	44.5	32.8	43.6	31.5	43.5	27.5	42.1
39.0	45.9	34.1	43.9	32.0	43.2	29.0	42.3
41.0	46.0	38.0	45.0	32.0	43.5	29.8	42.5
43.0	46.9	43.1	47.5	35.5	45.0	31.0	43.0
46.4	47.7	37.4	45.1	35.7	45.2	33.5	44.2
46.4	47.8	36.7	44.9	39.0	46.2	34.2	44.0
33.5	43.6	33.2	43.9	40.0	46.2	37.0	45.2
31.7	43.6	31.0	43.5	40.0	46.0	37.8	45.3
24.0	42.0	25.9	42.6	43.0	47.6	41.0	36.2
				43.0	47.5	41.0	36.3
				25.0	42.0	34.5	43.7
				24.5	42.0	34.0	43.7
						31.0	42.5
						30.0	42.8
						29.0	42.8
						24.2	42.0
						24.0	42.0

[1] Thermocouple. [2] Thermometer.

To verify this, I shut the cold-air pipe off entirely and changed the temperature of the hot air by passing more or less steam through this coil. Curves thus obtained showed greater regularity, and the break was nearly eliminated. Finally, by comparing these results with the datum obtained directly when the hot pipe is shut off and the cold one open, a difference of several degrees of t corresponded to a given value of θ for the two cases.

This shows the delicate balance which must exist between the temperature of the color tube at any point and the constants (temperature, flow, etc.) of the air supply. Thus in the chart, fig. 27, the two parts of the curves may actually fail to coalesce when the velocity of the air current without change of temperature is altered in an abrupt way. It does not seem probable, therefore, that the point of inflection can be referred to a special condensation phenomenon in the jet, an inference which I was at first inclined to countenance.

73. *Mean coefficients.*—These experiments point out certain shortcomings in the apparatus (fig. 14), for it now appears clearly enough that for a given influx hole, say 2 inches in diameter, the hot and cold conveyance pipes should be larger than 2 inches. They also show that any statment as to the effect of the temperature of the inflowing air on the temperatures of the color tube is incomplete without a qualifying statement as to the amount of air supplied—a state of things which one might easily anticipate, but I was not prepared for so large a discrepancy as that actually observed.

To obtain a datum for the effect of the temperature of the inflowing air in case of an influx pipe about 1 meter long and 2 inches in diameter, the means of the two branches of the curves Pl. IV and fig. 27 may be taken, for the manipulation was as follows: At the outset the cold valve was open and the hot valve closed. The latter was then gradually opened (increasing the air supply as well as the air temperature) until quite open. Then the cold valve was gradually closed (decreasing the air supply and increasing the air temperture) until quite shut off. The two branches of the curves thus represent symmetrical cases, assuming that when both valves are open at least as much air is furnished as can flow through the given influx pipe.

The following table contains the results:

TABLE 23.—*Mean coefficients for the effect of air temperature.*

P	H	$\frac{dt}{d\theta}$	Mean $\frac{dt}{d\theta}$	P	H	$\frac{dt}{d\theta}$	Mean $\frac{dt}{d\theta}$
30	8	.35	....	30	20	.04 .28	.16
32	20	.10 .37	.24	30	20	.08 .42	.25
31	34	.19 .36	.27	30	20	.07 .32	.20
33	46	.07 .51	.29	30	20	.11 .35	.23

Thus the temperature at any point of the color tube increases about 0.2° to 3° for each degree of increase of the temperature of the inflowing air, and throughout a distance of 8 cm. to 50 cm. above the nozzle. Near the nozzle ($<$ 0.4 cm. above it), where there is no mixing, the effect is nil. It is a maximum near the top of the tube, where mixture is most complete.

Summary.—With these experiments I have thrown about as much light on the color phenomena, seen by the aid of steam jets, as lies within the reach of this purely experimental method. A part of the work could have been refined, but such refinement would not, in my judgment, lead to any essential novelties, unless they relate to the delicate question of the temperature and saturation of the medium into which the jet is discharged.

All the evidence goes to show that the first stages of cooling are adiabatic, for the temperature of points of the steam jet lying near the nozzle is nearly independent of the temperature of the medium into which the jet discharges (section 72), so far as examined. The amount of cooling which takes place in this way is noteworthy, as well as the suddenness with which it takes place. There is little doubt in my mind that this adiabatic cooling would actually carry the jet to the point of condensation, even if the discharge took place into an absolutely dust-free medium. Thus the appearance of the jet in this case suggests itself as a means of obtaining collateral evidence, and the experiment is soon to be made. (Section 62.)

The second stage of cooling is due to intermixture with air. It is promoted by turbulent motion within the jet, and hence a rough nozzle (sections 44 to 46) or dust nuclei in the medium (section 38) precipitate condensation, so that the case of a perfectly smooth jet in a dust-free medium is again of interest. Here it seems that condensation would at first result as the direct effect of adiabatic cooling, and at the height of the condensation limit the molecules themselves became condensation nuclei.

As long as the cooling is merely adiabatic, many of the conditions[1] involved are open to computation. Let G be the entropy of a x kilograms of steam in intimate contact with $(1-x)$ kilograms of water, both at the same absolute temperature T, at which the specific heat of water is C and the latent heat of steam r. Then

$$G=\frac{rx}{T}+C\ ln\ T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where x is conveniently fractional.

If therefore there were no lag phenomenon or no supersaturation, this equation is sufficient to show the amount of water which would separate out of the jet at each of the stages of adiabatic cooling. Take, for example, the case of Table 19 ($H=0.4$ cm.), where the steam arrives at a pressure of $P=75$ cm. and an absolute temperature of $120°+273°=393°$ C., and at about 0.4 cm. above the nozzle is already cooled down to $100+273=373°$ C. of absolute temperature. Just before entering the nozzle the mixture is wholly vapor, and therefore

$$x=1;\ r=522;\ T=393°;\ C=1;\ \text{(nearly)}$$

whence $G=7.302$ as the entropy per kilogram of escaping steam.

---

[1] Cf. Bertrand: Thermodynamique, Chap. x, Paris, 1887.

At the distance 0.4 cm. above the nozzle this entropy can not have changed, in view of the rapidity of efflux. Hence $G=\text{constant}=7.302$, while

$$T=373^\circ;\ r=536;\ C=1.$$

Hence

$$x=(G-\ln T)\frac{T}{r}=0.960$$

$$(1-x)=0.040$$

or there must be about 40 grams of suspended water globules in each kilogram of the mixture of steam and water, in order to quite relieve the strain of supersaturation. It is instructive to trace this phenomenon further, supposing the steam which arrives at a temperature of 120° C. to be successively cooled in adiabatic stages of 20°. The following table contains the results.

TABLE 24.—*Condensation due to adiabatic cooling.*

[Steam initially at 120°. Entropy per *Kg.*, 7.30.]

Cooled to	Vapor present.	Water condensed.	Cooled to	Vapor present.	Water condensed.
°*C.*	*Kg.*	*Kg.*	°*C.*	*Kg.*	*Kg.*
120	1.00	0.00	40	0.84	0.16
100	.96	.04	20	.80	.20
80	.92	.08	0	.76	.24
60	.88	.12	−20	.72	.28

Hence, if there were no cooling by convection or mixture, the steam discharged into a medium of ordinary temperatures would continually condense. In general, however, the equation (1) is such that the quantity of vapor x, regarded as a function of T, must pass through a minimum. Nevertheless, the steam jet, in which there is both condensation and evaporation, owes the latter property to the solutional effect of the admixed air. Adiabatic expansion can alone increase the condensation, always supposing that the jet is initially vapor.

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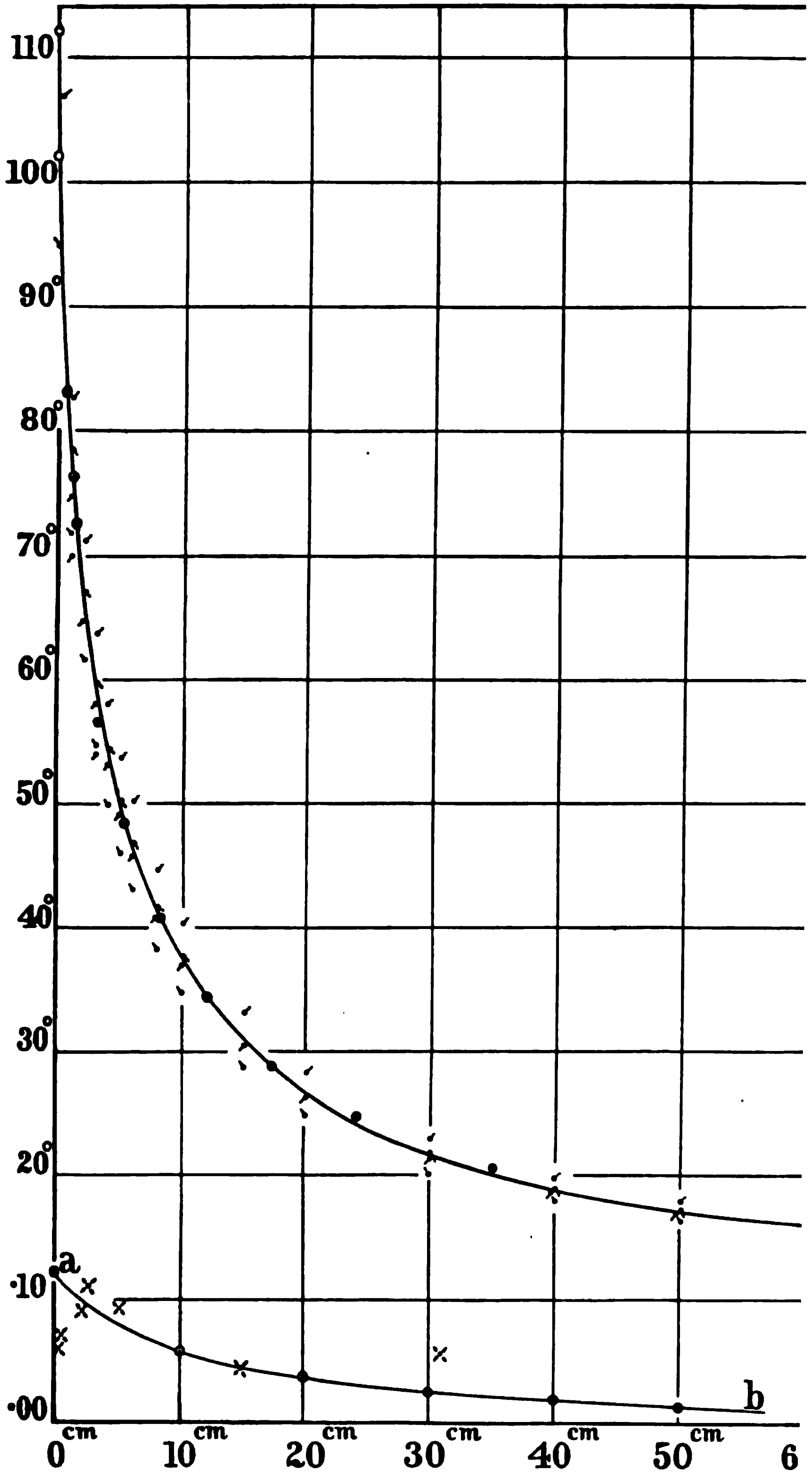

Curves *P*, distribution of temperature on passing through the nozzle indefinitely outward al
and the abscissas heights above the plane of the nozzle supposed to lie at the origin of co
Section 66.

Curves *a b* showing probable values for the pressure coefficients $\frac{d\,t}{d\,n}$ at different heights.

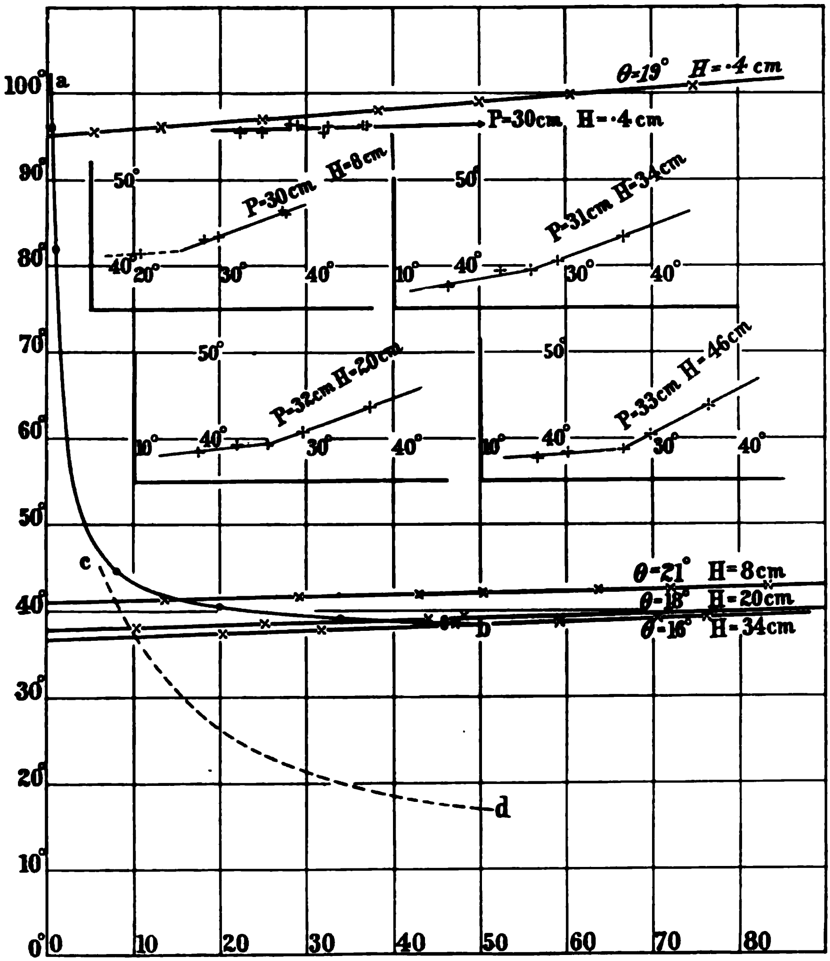

Chart showing the axial temperature in the color tubes, viz:

Curve *a c b*, axial distribution of temperature (ordinates) in terms of height (abscissas in cm.) above the nozzle.

Curve *a c d*, same for a free jet.

Curves *θ*, *H*, change of temperature (ordinates) at a given point (*H*) in terms of the actuating steam pressure (abscissas in cm. of mercury).

Curves *P*, *H*, change of temperature (ordinates) at a given point (*H*) in terms of the temperature of the inflowing air (abscissas in °C).

BULLETIN No. 13.

U. S. DEPARTMENT OF AGRICULTURE,
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TEMPERATURES INJURIOUS TO FOOD PRODUCTS IN STORAGE AND DURING TRANSPORTATION,

AND

METHODS OF PROTECTION FROM THE SAME.

BY

H. E. WILLIAMS,
CHIEF CLERK, FORECAST DIVISION.

Published by authority of the Secretary of Agriculture.

WASHINGTON, D. C.:
WEATHER BUREAU.
1894.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., November 10, 1894.

SIR: I transmit herewith the manuscript for a pamphlet entitled "Temperatures Injurious to Food Products in Storage and During Transportation and Methods of Protection from the Same," and respectfully recommend its publication as a bulletin of this Bureau for distribution to our observers and others interested.

Very respectfully,

M. W. HARRINGTON,
Chief.

HON. J. STERLING MORTON,
Secretary.

LETTER OF SUBMITTAL.

WASHINGTON, D. C., *October* 22, 1894.

SIR: The accompanying paper, entitled "Temperatures Injurious to Food Products in Storage and During Transportation, and Methods of Protection from the Same," which was prepared under your instructions, is submitted for publication. The paper includes the matter contained in the pamphlet entitled, "Protection of Fruits, Vegetables, and Other Food Products from Injury by Heat or Cold During Transportation," to which has been added valuable information as to the temperature conditions favorable to the safe-keeping of food products in storage, the slaughtering of cattle and hogs with a view to the subsequent preservation and curing of the meat, and suggestions as to how to best utilize the weather reports in connection with the safe storage and shipment of food products. It is proper to state that the suggestion which led to the preparation of the pamphlet referred to was received from Mr. A. F. Sims, Observer, Weather Bureau, Albany, N. Y.

The chief credit for the preparation of this paper is due to Mr. H. E. Williams, Chief Clerk of the Forecast Division, who prepared the circular calling for the information, and edited and arranged the matter.

Very respectfully,

H. H. C. DUNWOODY,
Assigned to duty as Acting Assistant Chief,
In charge Forecast Division.

MARK W. HARRINGTON,
Chief of Weather Bureau.

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TEMPERATURES INJURIOUS TO FOOD PRODUCTS IN STORAGE AND DURING TRANSPORTATION, AND METHODS OF PROTECTION FROM THE SAME.[1]

The object of this bulletin is to furnish information regarding the temperatures that are injurious to food products and other perishable articles, under different conditions and during shipment, and to suggest methods of protecting the same from extremes of heat and cold. This information is largely a compilation of the opinions of merchants and shippers in all parts of the country, which were received in reply to a circular letter sent out by the Weather Bureau, and contain much that will prove of interest and value to the public generally.

In the transportation of perishable freight there are three primal objects to be attained:

1. The protection of the shipment from frost or excessive cold.
2. The protection of the same from excessive heat.
3. The circulation of air through the car, so as to carry off the gases generated by this class of freight.

TEMPERATURES FOR SHIPPING PERISHABLE GOODS.

The temperatures at which perishable goods are liable to damage vary greatly with different commodities, their condition when shipped, how long they may be in transit, whether they are kept continually in motion, etc. Injury is liable to occur from long exposure to a temperature below 32°, or from a shorter exposure to a greater cold, so that the duration, as well as the intensity, of the cold must be considered.

The degree of cold to which perishable goods may be subjected without injury depends on the time the shipment will be on the road; also, whether it will be unloaded immediately upon arriving at its destination or allowed to stand some time, also direction of shipment, whether toward a cold area or away from it.

Shucked oysters shipped in their own liquor in tight barrels will not spoil if frozen while in transit. Thick or fat clams or oysters will not freeze as readily as lean ones, as the latter contain much more water. Oysters will not freeze as readily as clams. It is safer when oysters or clams in the shell are frozen to thaw them out gradually, in the original package, in a cool place. Clams and oysters in transit through a snowstorm will not freeze as readily as when the weather is fair and a stiff wind prevails.

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[1] The matter contained in the pamphlet entitled, Protection of Fruits, Vegetables, and Other Food Products from Injury by Heat or Cold during Transportation, is also included in this publication.

Shippers and agents concur in the statement that danger in transportation by freezing can be practically eliminated by the shipment of produce by modern methods; the lined car suffices in spring and autumn, and usually during the winter, while in extreme weather the Eastman heater car is used. The temperature of the produce when put into the car is quite a factor to be observed. If it has been exposed to a low temperature for a considerable time before, it is in a poor condition to withstand cold, and the length of time so exposed should be taken into account. It is also claimed that a car load of produce, like potatoes, will stand a lower temperature when the car is in motion than when at rest.

In ordinary freight cars perishable goods can be shipped with safety with the outside temperature at 20°, and in refrigerator cars at 10°. In the latter, these goods may be safely shipped with a temperature outside of from zero to 10° below, if the car is first heated, and at the end of the journey the goods are immediately taken into a warm place without being carted any great distance. The better class of refrigerator cars will carry all perishable goods safely through temperature as low as 20° below zero, provided they are not subjected to such temperatures longer than three or four days at a time, while with the ordinary refrigerator cars temperatures of zero are considered dangerous, especially if the goods they contain be of the most perishable kind.

Beer can be shipped at an outside temperature of 10° if placed in a refrigerator car and the kegs packed in hay or sawdust and fresh stable manure, the packing being 6 inches or more all around. Bottled beer that has passed through a low temperature during transit should be placed in a cellar and allowed to regain a normal temperature slowly, otherwise it is liable to spoil.

Roses and cut flowers will not be injured unless the temperature falls to 32°. Roses need as low a temperature as possible without freezing, because they are shipped as buds and would develop if the temperature were high.

As a rule, truckers will not haul vegetables to the cars for shipment when the temperature reaches 20°, or lower, and in no case when it is near 32°, if raining or snowing.

Articles shipped from the North to the South during winter should be in a perfectly dry condition.

In shipping early vegetables to a northern market from the South, for distances requiring more than forty-eight hours to cover, openwork baskets, slatted boxes, or barrels with openings cut in them, should be used to allow a circulation of air.

It is not safe to ship olives in any car, unless heated artificially, when the temperature is below 25°.

In shipping green meats the almost universal practice is to ship in refrigerator cars where the temperature can be maintained at any desired degree, a temperature from 36° to 40° being considered the best.

Fresh beef for shipping should be chilled to a temperature of 36°, although under favorable conditions it will arrive in a good state if chilled to only 40°. The cars should be at the same temperature as the chill rooms, and it is considered very important to have an even temperature from the time the beef is taken from the chill room until its arrival at its destination.

In shipping long distances in summer, it is necessary to re-ice the cars, the frequency depending on the prevailing temperature, so that no fixed rule can be given. In winter, the temperature is kept up to 36° by means of stoves or oil lamps.

If refrigerator cars are not used, the meat should be wrapped in burlaps and the carcasses hung so as not to touch each other. With an outside air temperature of 50°, or below, in dry weather, meat that has been thoroughly cooled will keep a week if shipped in an ordinary box car. Pork is injured more quickly by high temperature than other meats, and greater care should be taken with it in storing and shipping. Sudden changes in temperature of from 10° to 20° are very injurious to green meats and should be provided against when possible.

Poultry, if shipped at a temperature of 50° and up, should be packed in ice and burlaps; if under 50°, in dry weather, no extra precautions are needed,

Milk for shipping requires great care to prevent souring; it should be reduced after drawing to a temperature of 40°, which extracts the animal heat. It should never be frozen, as it becomes watery and inferior in quality when thawed out.

Butter should not be frozen unless it is to be used soon after thawing; it freezes at 15°, and when thawed becomes strong quickly.

It is important to note that in shipping fruits, etc., many of the precautions taken in packing to keep out the cold will also keep in the heat, and there is really more danger in some instances from heating by process of decomposition than from cold. All fresh fruit tends to generate heat by this process. A car load of fresh fruit approaching ripeness, closed up tight in an uniced refrigerator car with a temperature above 50°, will, in twenty-four hours, generate heat enough to injure it, and in two or three days to as thoroughly cook it as if it had been subjected to steam heat. Suitable refrigerator transportation must, therefore, provide for the heat generated within as well as to protect it from the outside heat. The perfection of refrigeration for fruit is not necessarily a low but a uniform temperature; a temperature from 40° to 50° will keep fruit for twenty or thirty days if carefully handled. Strawberries have been transported from Florida to Chicago, transferred to cold storage rooms, and remained in perfect condition for four weeks after being picked.

Fruit that has been subjected to a high temperature before being shipped should be cooled immediately after being loaded. Ordinary refrigeration will not cool a load of hot fruit within twenty-four hours, and during that time it will deteriorate in quality very much. It should be cooled in four or five hours in order to prevent fermentation.

Precautions taken in shipping to protect from cold are papering, packing in straw or sawdust, boxing, barreling with paper lining, shipping in paper-lined cars, refrigerator cars, and cars heated by steam, stoves, and salamanders.

Cars containing perishable goods are sometimes, when a north wind is blowing on the prairie, covered with canvas on the north side.

In winter time refrigerator cars are used without ice in forwarding goods from the Pacific coast, and in passing through cold belts or stretches of country the hatches are closed, and the cars being lined and with padded doors, the shipment is protected against the outside temperature; but in passing through warmer climates the ventilators of cars are opened in order to prevent the perishable goods from heating and decaying.

It is stated, however, that for the shipment of fruit the ordinary refrigerator car is not entirely satisfactory, and that there is a strong demand for a better refrigerator car than can now be obtained.. A car is wanted that will carry oranges, bananas, etc., without danger of chill through the coldest climates of the country, as the delays in housing are injurious to the keeping properties of the fruit, and the dealer is also kept out of the use of his goods.

To protect goods shipped in an ordinary car the sides of the car should be protected by heavy paper tacked to the wall and by the addition of an inner board wall a few inches distant from the other one. A car thus equipped and packed with produce, surrounded by straw, will retain sufficient heat to prevent injury for twenty-four hours, the average air temperature of all parts of the car being at least 12° higher than that of the outside air. Cars are sometimes warmed by steam from the locomotive when in motion, and by stoves when steam is not available. Cars after being loaded are carefully inspected as to temperature within, their destination considered, and if the weather is exceedingly cold, or is liable to be, the car is often accompanied by an attendant; otherwise it is inspected from time to time on the road. Lined cars, that is, cars lined with tongued and grooved boards on the sides and ends, are considered the best by heavy shippers of potatoes, as they can be heated by an ordinary stove, and will stand a temperature outside of 20° below zero, when a man is in charge to keep up the fires. The potatoes are packed in straw, bulkheaded back, center of car left empty, and car filled as high as double lining; when the temperature is 12°, or more, below freezing, the rule is to line the barrels with thick paper, and at extremely low temperatures, as a matter of extra precaution, the barrels are covered over the outside with the same kind of paper, which is considered the best known protection from frost.

Oranges shipped from Florida to points as far north as Minnesota are started in ventilator cars, which are changed at Nashville to air-tight refrigerator cars, the ventilators of which are kept open, provided the temperature remains above 32°, until arrival at St. Louis, from which point the ventilators are closed and the cars made air tight.

Oranges loaded in ventilated or common cars should be transferred to refrigerator cars when the temperature reaches 10° above zero; in transit, with a falling temperature, the ventilators should be closed when the thermometer reaches 20°, and with a rising temperature the ventilators should be opened when it reaches 28°. For lemons the minimum is 35° for opening and closing the ventilators, and for bananas 45° for opening or closing. Some shippers say that ventilators on cars containing bananas, lemons, and other delicate fruits should be closed at a temperature of 40°. In shipping car loads of bananas, a man is usually sent in charge to open and close the ventilators. Bananas should be put in a paper bag and a heavy canvas bag, and then covered with salt hay, but when put in automatic heaters the fruit is packed only in salt hay.

French mustard and aqua ammonia are packed in sawdust and securely boxed, being careful to allow the sawdust to form a layer between the articles and the side of the box.

Eggs are packed in crates with separate pasteboard divisions, with a layer and a cover of oat chaff.

Quinces, apples, onions, and pears are packed in barrels, each layer of barrels covered with and resting on straw.

Tomatoes, lemons, and oranges are packed in crates; each layer of crates in the car is covered by and rests upon straw, usually bulkheaded back from the door and car full.

Shrubs and fruit trees are laid on straw, covered with it on all sides, and car packed full.

Flowers are packed in moss and car filled.

Flowers, shrubs, and trees should have their roots carefully packed in straw and the roots placed together in two or three piles, so as to protect them; if the roots are killed they are of a uniform black; if only injured by frost the root is pinkish in color just below the outer covering, and if sound they are of uniform white. Even if of a dark pink color no damage need result, if the frost is gradually thawed out by the trees being left in the closed car for four or five days, or else put the roots well down in the soil in a horizontal position and thaw out gradually. Extra precautions are taken with trees, etc., when passing over mountains, and no shipments should be made when the temperature is likely to be zero anywhere in the higher regions.

During cold weather oysters and clams should be shipped in tight barrels lined with paper.

Products sent loose in a car are packed in straw on all sides, particular attention being paid to the packing around doors, and to see that the car is full. Certain classes of goods, embracing peaches, melons, and grapes, are taken by some railroads in no other way.

In shipping perishable goods it is well to cover them with two sheets of heavy paper, weighing about 1¼ pounds each. Manure is largely used to protect perishable goods, the bottom of the car being thickly covered with it, and in some cases it is put on top of the goods.

The relation between the outside air temperature and the temperature within the car varies largely, depending on the kind of car, whether an ordinary freight or refrigerator car, whether lined or not, whether standing still or in motion, and also on the weather, whether windy or calm, warm or cold.

In an ordinary freight car the difference ranges from 2° to 15°, and in a refrigerator car from 15° to 30°. If the latter be provided with heating apparatus, the temperature in winter can be kept at any required degree. For ordinary winter weather, the temperature ranging from 10° to 30° above zero, the refrigerator cars may be used for shipment to any distance without being heated.

From six observations taken at intervals of ten minutes it was found that on a warm day, when the mean of the six readings outside was 68°, it was 66° on the inside of an ordinary freight car and 63° inside of an uniced refrigerator car. On a cold day the mean of six observations was 38° outside and 35° inside of an ordinary car, and 36° inside of a refrigerator car; the car was stationary.

Freight from the Pacific coast to the Mississippi Valley, or to the Atlantic coast, has to pass through several varieties of climate at any time of the year. It is therefore obvious that at one time the temperature inside of the car will be materially above the outside temperature, while perhaps a few hours later it will be below.[1]

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[1] NOTE.—Under date of November 15, 1894, a San Francisco paper publishes an account of an experimental trip from Oakland, Cal., to New Orleans, La., and return, of a refrigerator car loaded with fruits and flowers in which sterilized air was used as a preservative instead of ice. The trip occupied fifteen days, and it was stated that on opening the car hardly an article showed the slightest indication of decay. It was claimed that the cost by this method for such a trip would be $175 per car less than that entailed by the use of ice.

FOOD PRODUCTS IN STORAGE.

The best storage for apples and potatoes and for vegetables generally is a well-ventilated, dry cellar kept at a temperature between 30° and 45°. Other methods of storing potatoes in winter are: In tent-shaped houses, ventilated at the top and covered with earth from 6 to 12 inches deep; packing in shallow pits in the ground between layers of straw or cornstalks, a layer of straw or cornstalks on top covered with earth, a hole being left in the top for ventilation; and packing in dry sand in cellars.

Apples and potatoes are also stored in specially constructed barns, made as nearly air tight as possible, fitted with crates or bins, and supplied with heating apparatus for maintaining an even temperature.

Apples keep better if, before storing, they are put in piles out of doors and allowed to sweat.

Potatoes should not be left in the sun after being dug, as the heating induces sweating and decay.

Celery is stored in an unfloored, inclosed, well-ventilated shed, the earth is well wetted, and the celery packed in an upright position, with narrow lanes about 2 feet apart for ventilation. The temperature should be kept as near 32° as possible; a temperature of 60° to 65° injures it.

Young fruit trees, flowering shrubs, and plants are injured by temperatures below 36°. They are stored in cellars packed in straw, and generally shipped in the same manner as potatoes as regards packing.

Where fruits, vegetables, etc., are kept in cold storage, the following temperatures are considered most favorable, viz, for apples, apricots, berries, buckwheat flour, oatmeal, corn meal, cider, cheese, cranberries, onions, dried or salted fish, furs, and woolens, 34° to 36°; for sauerkraut, brined meats, lard, maple sirup, dried fruits, dried corn, peas, beans, etc., 40° to 44°.

Oranges on the trees will stand a temperature of 26° for an hour or so, but if exposed to that temperature for four hours will freeze inside. Oranges slightly frozen, when placed in a cool room and thawed out gradually, are sweetened, and considered by some people as improved, but when frozen solid and thawed they have a sickish sweet flavor. When oranges have been frozen they can be thawed without injury by putting them in cold water or tight barrels immediately after arrival, and allowing them to thaw out gradually.

The temperature to which lemons, oranges, and bananas may be exposed without damage, varies in different localities, and the different temperatures at those points seem to depend a great deal on the moisture.

Tropical fruits in storage should be kept in rooms with the temperature between 60° and 70°.

While a temperature as low as freezing (32°) will not injure potatoes for eating purposes, yet they will fail to sprout in the spring.

Wines should not be subjected to a temperature lower than 20° or higher than 72°.

Fruit wrapped in heavy brown paper will stand 15° more cold than if not wrapped.

Eastern grapes bear low temperatures better than California or Malaga.

Canned tomatoes when frozen become stringy, canned fish soft and mushy, lemons black and spotted, olives soft and rancid, pickles soft and unsalable.

It appears to be generally conceded that goods, when free from undue dampness, that is, those classed as dry, will stand a much lower degree of temperature without injury than when moist.

Sauerkraut ferments at 90° and freezes at 15°, either of which conditions spoils it.

All tree seeds, including peach, plum, walnut, etc., sprout better in the spring if frozen during the winter. Bulbs, including tulips, lilies, and hyacinths, are not injured if subjected to a temperature below zero.

Cut flowers will keep three or four days in a temperature a little above freezing.

Fruit should be kept free from decaying matter and filth of all kinds. A spraying apparatus for cleansing choice fruit with water has been found of value. Electric fans for ventilating have been used to advantage. A free exposure to the night air, especially when conditions are favorable for a heavy dew, is conducive to the preservation of both fruit and vegetables.

Oysters in shell can be kept for two months in a dark place when the temperature is but little above freezing if occasionally sprinkled with ice water. Fresh oysters in cans deteriorate after two weeks in any temperature unless frozen.

Fresh fish are stored and shipped in bins with cracked ice, the ice water running over them to keep them moist. Northern merchants sometimes freeze fish for storage and transportation, but they spoil more quickly after being thawed, and it is claimed that the flavor is injured by freezing. Oysters, if likely to be exposed to very low temperatures, should not be washed.

TEMPERATURES FAVORABLE FOR SLAUGHTERING CATTLE AND HOGS AND THE PRESERVATION AND CURING OF THE MEAT.

In the slaughtering of cattle and hogs, and the subsequent curing and preservation of the meat, the temperature of the air and of the dressed meats is an important factor to be considered. Opinions differ somewhat on some points as to the most favorable temperatures for these purposes, but the following are considered reliable:

Animals should never be killed while in an overheated or excited state, but should be kept quiet for twenty-four hours previously and fed lightly on cooling food. Where cold storage rooms are available in which the meat can afterwards be reduced to any required temperature, the killing may be done without injury in any weather; otherwise, a cool, dry day, with the temperature not above 45° or 50°, nor below 20°, is the most favorable. If the weather is wet or damp, the temperature should not be above 35° or 40°. The killing may be done in warmer weather than this if the temperature on the following night falls to 40°, or below. After killing, the carcasses should be hung without touching each other and allowed to remain for twenty-four hours, or more, until the animal heat has passed off and the temperature is 40°, or less, throughout. Meat thus treated may be shipped or kept for days in a temperature of 45°, or below, in dry weather; 40°, or below, in wet. When the night following the killing is warm, the hindquarters of beeves are sometimes slit open to allow them to cool more rapidly. Temperatures above 50°, with moist air, damage green meats very quickly. Meat, and particularly pork, that has been frozen and afterwards thawed does not keep as well as that which has been simply chilled. Pork intended for curing should never be frozen.

The following extract from a letter from a Southern State is given as of interest in this connection:

"*Cause of meat spoiling.*—First place, the slaughtering is done during the coldest days and the meat hastily cut up next morning, sometimes a bit frozen, then salted in an outhouse. Now, if several freezing nights come right after the butchering, the intelligent farmer expresses himself in luck so far as having an ample supply of meat for the coming summer. By and by he thinks it enough time in salt, takes it up, hangs it, and begins the smoking. In about a week he takes the good wife to the smokehouse, shows the plump hams; so far so good. Well, wife cooks one of the hams to see how it is cured; then he finds that he has got a nice lot of gasometers that gives off an odor that the good wife can't tolerate. The trouble is all his own fault. The meat may have frozen through, or at least the salt had frozen, then become caked, and then the action of penetration ceased; but nature does not wait, inside along the bone a gas forms which, if it were just warm enough, the salt would take up and absorb; but, instead, the salt has hermetically sealed it and keeps it in; then the meat takes it up and holds it insoluble until the air can get to it; then decomposition takes place."

It is stated that frozen meat will spoil in sixteen hours if subjected to a temperature of 75°. In the Northwestern States, where the climate is dry, the farmers, between November 15 and February 15, hang green meats in the open air protected from the sun and use from them as occasion requires; meat thus kept is very tender and more palatable than that fresh killed. Meat hung up in the open air until the animal heat has passed off is said to keep better than that placed in cold storage immediately after being killed, and it is better to follow this method, if practicable, even where cold storage is available. After the animal heat is all out the meat should be put into coolers at a temperature of 50°, and the temperature gradually lowered for forty-eight hours, until it reaches 36°, and then raised slowly to 38°. The principal injury to beef products is stated to occur from sending it from the slaughter house to the chill room before the animal heat has entirely left the carcass; this closes the pores and the meat retains heat and turns sour. From 36° to 42° is the best temperature for storage rooms for dressed meats.

In the case of pork intended for curing, with cold storage available, it is found that a temperature which will reduce the carcass within a period of forty-eight hours to 36°, to 39° at its thickest and most vulnerable points, viz, the center of the ham and shoulder, is the most desirable. At a temperature of 40° a percentage of taint is liable to develop, and at anything over that temperature tainted meat develops rapidly. Of course it is necessary to create an atmosphere considerably under these temperatures in order to bring down the temperature of the inside of the carcass at its thickest part to the above figures, and, therefore, it is found desirable to carry the chill rooms at temperatures about 33° to 35°. It is undesirable to reduce the meat to a very low temperature, as its solid and hard condition retards the action of the salt in penetrating to the center of the piece, and thus causes the process of curing to be slower and less effective. Attaining too low temperatures has been productive of serious loss to curers, as well as failure to obtain sufficiently low temperatures, from the fact that when meat is over-chilled before the curing process begins and taken out after sufficient time has been allowed to thoroughly cure it, were the conditions right, owing to the causes stated, the cure has been retarded, and when exposed to the ordinary atmosphere at warm seasons it becomes spoiled. Some large packers place the hogs after being killed in a temperature of from 45° to 50° for twelve to fifteen hours, and then in a temperature of 35° to 40° for twenty-four to thirty-six hours. According to some experienced authorities the carcasses should not be cut until thoroughly cooled, otherwise the meat is apt to sour. The curing should be done in storage rooms with the temperature about 40°, the length of time for curing depending on the cut and weight of the meat, and ranging from fifteen to seventy-five days. Storage rooms cooled by the expansion of gases in tubes are considered better than those cooled by ice, on account of being drier. Dry salt pork for southern use in winter needs to be cured in salt for thirty days, but for summer use it should have from fifty to sixty days' curing. Smoked meats for southern use need to be more thoroughly cured than other kinds, as the heating in smoking tends to damage them.

The most favorable conditions for the preservation of green or cured meats for a considerable length of time are found in storage rooms kept at a uniform temperature of from 36° to 40° with a good circulation of dry air.

THE USE OF THE WEATHER REPORTS IN CONNECTION WITH THE SAFE STORAGE AND SHIPMENT OF FOOD PRODUCTS.

In connection with the storage and shipment of food products liable to injury by heat or cold, much benefit may be derived from an intelligent use of the information contained in the daily weather reports and forecasts published by the Weather Bureau, which show the temperature conditions prevailing over the whole country at the time of the observations, the highest and lowest temperatures that have occurred during the past twelve hours, and the probable conditions that will prevail during the next twenty-four or thirty-six hours. These reports and forecasts are received at nearly every Weather Bureau office, of which there is one or more in nearly every State and Territory, and published on maps and bulletins, which are posted in conspicuous places in the city where the office is located and mailed to surrounding towns. The reports, or a synopsis of them, are also generally published in the daily papers.

Fuller information than is obtainable from either of these sources may be had at the Weather Bureau office itself from the observer in charge, or, where none of these means are available, arrangements may be made with the observer to supply special information by mail, telephone, or telegraph. In the large cities of the country, dealers in this class of produce are guided in their transactions very largely by the information thus obtained. The temperature of the region to which shipments are to be made is carefully watched and the shipment expedited or delayed according as the conditions are favorable or unfavorable, and shipments on the road are protected from injury by telegraphic instructions as to the necessary precautions to be taken. As shipments in ordinary box cars, or as freight, are less expensive than in refrigerator cars, or by express, advantage is taken of a favorable spell of weather to use the former methods.

In shipping early vegetables north from southern ports the weather reports are utilized to determine whether to use water or railroad transportation, the former being the cheaper. Dealers in certain kinds of produce, by careful attention to the daily weather reports and the weekly crop bulletins, keep themselves informed as to the sections where conditions most favorable for large crops have prevailed, and are thus enabled to judge of the probable supply and to know where to purchase to advantage.

As illustrations of the manner in which advantageous use may be made of the weather reports, suppose a merchant in Ohio has an order in January for a load of apples or potatoes to be shipped to St. Paul; when his shipment is ready he will, if wise, ascertain by personal inquiry at the Weather Bureau office, or by a study of the published reports and forecasts, the probable temperature conditions between Ohio and Minnesota for the period that the shipment is likely to be on the road and will regulate the same accordingly. If neither of these means of information is accessible to him, he may telegraph the observer at the nearest Weather Bureau office, Cincinnati, Columbus, Cleveland, Sandusky, or Toledo, as the case may be, requesting the information, or he may arrange beforehand with the observer to be informed by telegraph when the conditions are favorable for making the shipment, the cost of all telegrams, of course, to be borne by himself. While the consignment is on the road he should still keep himself informed as to the temperature conditions of the region through which it passes, and if injuriously low temperatures are likely to occur, may telegraph to have it housed or otherwise protected until the conditions are again favorable. By the use of similar means, a packer having a large number of hogs to slaughter may ascertain in advance when temperatures favorable for that purpose are likely to prevail in his locality; or a southern merchant having a consignment of tropical fruit on the road to the north may insure its protection from injuriously high or low temperatures by telegraphic instructions as to the opening or closing of ventilators, or the use of ice or artificial heat.

During the season when cold waves are liable to occur, a careful watch of the reports and forecasts will often enable dealers and others to protect from injury large quantities of produce in storage. Instances are numerous where the use of the information aforementioned has resulted in large pecuniary benefit.

The lowest and highest temperatures to which perishable goods may be subjected without injury under the conditions stated.

Perishable goods.	Lowest outside temperature.			Temperatures above which injury occurs.	Remarks.
	Articles in ordinary packages unprotected.	In ordinary freight cars.	In refrigerator or specially prepared cars.		
	°	°	°	°	
Apples, in bbls	20	10	—10	75	Covered with straw.
Apples, loose	28	15	—10	75	Packed in straw.
Apricots, baskets	35	24	10	70	
Aqua ammonia, bbls	30	20	—10	......	
Asparagus	28	22	....	70	In boxes covered with moss.
Bananas	50	32	....	90	In bulk and in boxes with straw.
Beans, snap	32	26	....	65	In barrels or crates.
Bear	Zero.	—20	....	65	Shipped loose.
Beer or ale, kegs	25	20	Zero.	75	Packed in manure and shavings.
Beets	26	20	....	70	In crates.
Bluing	30	20	—10	......	
Cabbage, early or late	25	20	Zero.	75	Barrels or crates.
Cantaloupes	32	25	10	80	
Cauliflower	22	15	....	70	In barrels with straw.
Celery	10	Zero.	....	65	Packed in crates.
Cheese	30	25	10	75	
Cider	22	18	—10	70	
Clams, in shell	20	10	—10	65	In barrels.
Cocoanuts	30	20	Zero.	90	In barrels or crates.
Crabs	10	Zero.	....	65	In baskets and barrels.
Cranberries	28	20	Zero.	......	
Cucumbers	32	20	....	65	In boxes with moss.
Cymlings, or squash	32	22	....	75	In crates.
Deer	Zero.	−20	....	65	Shipped loose.
Drugs (non-alcoholic)	32	28	Zero.	......	
Eggs, barreled or crated	30	20	Zero.	80	
Endive	10	Zero.	....	70	Packed in boxes or crates.
Extracts (flavoring)	20	15	Zero.	......	
Fish	10	Zero.	....	65	In barrels always iced.
Fish, canned	18	15	—10	......	
Flowers	35	20	—10	......	Packed in moss.
Grapes	34	20	Zero.	......	Packed in cork.
Grape fruit	32	20	Zero.	......	
Groceries, liquid	32	20	Zero.	......	
Ink	20	15	—10	......	
Kale	15	Zero.	....	65	Packed in boxes or crates.
Leek	28	20	....	65	Packed in boxes.
Lemons	32	20	10	75	In boxes or crates.
Lettuce	26	15	....	70	In crates or boxes.
Lobsters	25	20	Zero.	......	
Mandarins	32	20	Zero.	75	In boxes.
Medicines, patent	32	28	Zero.	......	Packed in sawdust.
Milk	32	28	Zero.	75	
Mucilage	25	15	Zero.	......	
Mustard, French	26	20	—10	......	
Okra	25	20	....	75	In baskets or boxes.
Olives, in bulk	28	25	Zero.	......	In barrels.
Olives, in glass	25	20	Zero.	......	
Onions, boxes	20	15	Zero.	......	
Onions	20	10	....	80	In barrels, boxes, or crates.
Oranges	28	20	Zero.	80	In baskets, boxes, barrels, or crates.
Oysters, in shell	20	10	—10	65	In barrels.
Oysters, shucked	30	20	Zero.	70	In barrels.
Parsley	32	20	....	75	In baskets.
Parsnips	32	20	....	70	In baskets or barrels.
Partridges	10	Zero.	....	65	In bunches in boxes.
Paste	32	25	10	......	In barrels.
Peaches, fresh, baskets	32	20	10	80	
Peaches, canned	20	15	Zero.	......	
Peas	32	20	....	80	In baskets or barrels.
Pickles, in bulk	22	18	—10	......	In barrels.
Pickles, in glass	20	16	—10	......	
Pineapples	32	25	Zero.	75	In barrels, in crates, or in bulk.
Plums	35	32	Zero.	75	In boxes with paper.
Potatoes, Irish	33	25	10	80	In barrels or baskets.
Potatoes, sweet	35	28	10	80	In barrels or baskets.
Radishes	20	15	....	65	In baskets.
Rice	20	10	....	90	In barrels and sacks.
Shrubs, roses, or trees	35	10	—10	......	In canvas or sacking.

The lowest and highest temperatures, etc.—Continued.

Perishable goods.	Lowest outside temperature. Articles in ordinary packages unprotected.	In ordinary freight cars.	In refrigerator or specially prepared cars.	Temperatures above which injury occurs.	Remarks.
	°	°	°	°	
Spinach	15	15	....	75	In barrels or crates.
Strawberries	33	25	—10	65	
Tangerines	25	15	Zero.	70	In boxes.
Tea plants	28	20	....	95	Packed in boxes.
Thyme	20	10	....	90	In small baskets.
Tomatoes, fresh	33	28	10	90	
Tomatoes, canned	28	25	— 5	75	In boxes.
Turnips, late	15	Zero.	....	75	In barrels.
Vinegar, bbls	22	18	—10	......	
Watermelons	20	10	....	85	In barrels and in bulk.
Waters, mineral	28	25	Zero.	......	
Wines, light	22	15	Zero.	......	
Wild boar	Zero.	—20	....	65	Shipped loose.
Wild turkey	Zero.	—20	....	65	Shipped loose.
Yeast	28	25	Zero.	65	

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U. S. DEPARTMENT OF AGRICULTURE.
WEATHER BUREAU.

REPORT

OF THE

THIRD ANNUAL MEETING

OF THE

American Association of State Weather Services,

COÖPERATING WITH THE WEATHER BUREAU,
U. S. DEPARTMENT OF AGRICULTURE.

PUBLISHED BY AUTHORITY OF THE SECRETARY OF AGRICULTURE.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., November 14, 1894.

SIR: I have the honor to request authority to have printed, in pamphlet form, 10,000 copies of the accompanying proceedings of the third annual convention of the American Association of State Weather Services, held in Brooklyn, N. Y., August 17, 1894, in conjunction with the American Association for the Advancement of Science. It is desired to distribute the pamphlets to the voluntary observers and crop correspondents, and it is believed they will prove of service in attracting attention to the weather crop work of the Bureau and result in making its value more widely known.

The Association of State Weather Services is composed largely of officials of the Weather Bureau, and was organized in 1892 with a view to increasing the usefulness of Weather Bureau work. The proceedings of the two former meetings have been published by the Bureau. Very respectfully,

H. H. C. Dunwoody,
Acting Chief of Bureau.

Hon. J. Sterling Morton,
Secretary of Agriculture.

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THIRD ANNUAL CONVENTION OF THE AMERICAN ASSOCIATION OF STATE WEATHER SERVICES.

The third annual convention of the American Association of State Weather Services was held in Brooklyn, N. Y., August 17, 1894, in conjunction with the American Association for the Advancement of Science.

The call for this meeting was made June 8, 1894, by Maj. H. H. C. Dunwoody, president of the association, and a list of subjects for discussion issued July 23. While the number of States represented at the Brooklyn convention was smaller than at the two preceding conventions, the meeting was a very successful one. Had the place of meeting been more centrally located, the attendance would doubtless have been larger than at either of the preceding meetings. Notwithstanding the location of Brooklyn on the extreme eastern border of the country, one of the Pacific-Coast States and four others west of the Mississippi River had their State weather services represented at this convention. Several State weather-service directors not in attendance had expressed their intention to be present, but were prevented by circumstances beyond their control. Besides the president and secretary of the association, the following State weather-service officials were present and participated in the proceedings of the convention:

WEATHER-SERVICE OFFICIALS IN ATTENDANCE.

Mr. F. H. Clarke, director, Arkansas weather service.

Mr. T. B. Jennings, director, Kansas weather service.

Mr. Frank Burke, director, Kentucky weather service.

Mr. R. E. Kerkam, director, Louisiana weather service.

Dr. C. P. Cronk, meteorologist in charge Maryland weather service.

Dr. R. J. Hyatt, director, Mississippi weather service.

Mr. E. W. McGann, director, New Jersey weather service.

Mr. R. M. Hardinge, assistant director, New York State weather bureau.

Mr. B. S. Pague, director, Oregon weather service.

Mr. S. W. Glenn, director, South Dakota weather service.

There were also present the following named Weather Bureau officials: Messrs. E. B. Dunn, I. W. Brewer and W. L. Day, of the New York station, and Mr. John W. Smith, of the Boston station.

The president and the directors of the several services were much pleased at the presence of Prof. George C. Sonn, Newark, N. J., Mr. C. L. Swain, C. E., Boonton, N. J., and Mr. John Neagle, Plainfield, N. J. These gentlemen are enthusiastic voluntary observers of the New Jersey weather service, and their attendance at and participation in the proceedings of the convention was especially gratifying to the president of the association and the several directors present. The president called the meeting to order at 10.20 a. m., and after appropriate preliminary remarks addressed the meeting as follows:

ADDRESS OF THE PRESIDENT.

At the last annual meeting of the American Association of State Weather Services, official duties enforced my absence, greatly to my regret. It is therefore with more than uncommon pleasure that I am able to be with you upon the occasion of the third annual meeting of the Association of State Weather Services.

The expansion and development of these services to a degree scarcely anticipated by the most ardent advocate of the system make it desirable, if not absolutely necessary, that those who have this important work in hand should meet in convention for the purpose of discussing ways and means of furthering their work. That former meetings have been productive of great good is amply attested by the rapid progress that has been made in the several lines of work during the two years that have passed since the establishment of this association. It is equally evident that this and future conventions will continue to produce good results. It is profitable for us to meet from time to time, to learn from discussion and personal inquiry as to the methods of work employed in the several States, that each official may return to his field of operations better prepared to prosecute and extend his work. The published proceedings of past conventions have been eagerly looked for by the State service officials not fortunate enough to attend the meetings of the association, and the valuable information that has been given through these published proceedings concerning exposure of instruments and other essentials in observation work have contributed much toward creating and increasing interest in meteorological subjects.

With about 3,000 voluntary observers taking observations of temperature and rainfall and recording miscellaneous meteorological phenomena it is possible to supply, through the State weather service, climatological information for almost any locality in the United States. Nearly every county in the whole country is now provided with a station equipped with instruments of the Government standards, and if the work of establishing new stations continues during the next two years at the same rate as during the past two years, there will not be a county within the limits of our country that will not have a meteorological station.

Since the last annual convention of State weather services, which took place in Chicago, August 21 to 25, 1893, the work of State weather-service organization has gone rapidly forward, and the past twelve months in some of the more important lines may be marked as an era of exceptional progress. While there has been a decided extension in all the branches of work conducted by these organizations, the weather-crop service and the dissemination of forecasts have received greatest attention, and in these two lines have the most marked successes been achieved.

The weather-crop service of the National bureau now undoubtedly ranks next in importance to the work of making forecasts. The system of gathering reports upon which the weather crop bulletins are based has been so perfected in recent years that further improvement in some States can scarcely be expected. The crop bulletins of the States have been improved and are now more complete than at any previous time, and the increased circulation that these bulletins has attained amply attests their value. It is believed that there is no other class of information to which so much space is devoted in the public press to-day. A file of these bulletins for all the States for a year will form a most complete history of the weather conditions attending the growth and development of the several crops throughout the country.

More than 10,000 crop correspondents are to-day coöperating with the national weather service through the State organizations, 3,000 voluntary observers are furnishing monthly reports of daily observations of temperature and rainfall, and over 11,000 persons assist in the work of distributing the weather forecasts of the national weather service. This latter work has been more rapidly pushed during the past year than any other feature of State weather-service work, and it is expected that during the ensuing year the already large number of communities receiving the Government weather forecasts will be further increased from 5,000 to 6,000. With a continuation of the present liberal policy of the Honorable Secretary of Agriculture and the Chief of the Weather Bureau toward these services, there will be in a comparatively short time no important agricultural community in the United States, with the proper mail facilities, that will not receive the benefits of the forecasts.

The monthly reports of many of the States are model publications of their kind. It is to be hoped that in those States where as yet the more approved methods of publishing meteorological data are not practiced, means may be found by which their reports may be improved and raised to the standard attained where better facilities have been available. Uniformity in size, as far as practicable, and strict uniformity as to tabular data are very desirable. A daily record of temperature and rainfall for purpose of detailed investigation is most essential, and these should, if possible, form a part of each report.

It is believed that nothing can contribute more toward securing reliable and accurate observations than an inspection of the voluntary stations, that the observers may be made thoroughly acquainted with the proper conditions of instrumental exposure and be informed as to other essentials connected with their work.

It is to be hoped that at future meetings there will be not only a large representation of State weather service officials, but that many voluntary observers, crop correspondents, and displaymen may be present.

After correspondence and personally consulting with officials of the American Association of State Weather Services, a programme of subjects for discussion at this meeting has been formulated and published. No doubt other important matters not therein enumerated will be suggested by members present and will receive your careful consideration.

Having originally suggested the organization of State weather services, and having watched with keen interest their rapid growth for more than a decade of years, I shall not in the future lose that interest I have always taken in their operations, believing that the State weather service affords the most effective means of reaching the masses of people with information collected by the National Weather Service. I will conclude my remarks by expressing to the members of the association my thanks for the honor they have twice conferred by electing me their president.

TOPICS FOR DISCUSSION.

Topics for discussion at the third annual convention of the American Association of State Weather Services are the following:

1. Crops, in relation to normal or abnormal conditions of temperature and rainfall during the periods of growth and development. Can not State weather services collect and utilize statistics as to the conditions of rainfall and temperature under which full, average, or short yield of the various crops are produced?
2. Day of issue of the National and State weather crop bulletins. What can be done to increase the value of these publications?

3. Would it not be of advantage to each State weather service center to have actual (not interpolated) daily normals of temperature and rainfall for all weather bureau stations within its territory?

4. Is Form No. 1053 Meteorological the best that can be adopted for the reports of weather crop correspondents? Should Form No. 1067 Meteorological provide for an expression of opinion by displaymen as to the verification of forecasts?

5. Monthly publications of State weather services:

(*a*) Should the publication of monthly reports containing advertisements be encouraged?

(*b*) Publication of daily temperatures and precipitation—are data published in this form used sufficiently to justify continuance of their publication? Could the cost of same be expended to better advantage for permanent detailed records for each station, to be filed at the central station, where all requests for data might be met?

(*c*) Is it not important that, as far as practicable, uniform methods of graphic illustrations of meteorological conditions be adopted?

6. Dissemination of weather forecasts:

(*a*) Distribution of forecasts through the mails by logotype system.

(*b*) Are not the objections to the present plan of telegraphing to flag display and whistle signal stations forecasts of decided weather changes only, such as to justify the increased expense of returning to the former system of daily telegrams?

(*c*) Should the present system of flag displays be continued?

(*d*) Could a night signal be employed to advantage, and can the system of sound signals be extended?

7. Inspection of voluntary stations.

8. What should constitute the instrumental outfit of a voluntary meteorological station?

After the address by the president of the association, the several subjects were discussed in the order proposed in the programme.

TOPIC NO. 1.

Major DUNWOODY. I have given much attention to this subject in recent years, having prepared a number of charts giving for each State the actual rainfall, temperature, cloudiness, and humidity determined from the records of the Weather Bureau. Of course, these charts were necessarily more or less incomplete, owing to lack of data. They covered ten years and gave monthly averages, with departures from normal, represented graphically, so that the eye could readily discern the regions of excess or deficiency. In the same manner the departures from the average yield of the several crops were given, the regions where more or less than the average yield being illustrated by colors. By these charts the character of the yields and the meteorological conditions under which the crops were produced can be compared and studied. In the preparation of the charts referred to, a great difficulty was experienced from the unsatisfactory character of the data obtainable as to yields of many of the crops grown, but as to corn and some other staples it was possible to determine the conditions that it was desired to illustrate.

It is thought that more satisfactory conclusions might be deduced if, instead of attempting to give these data for the whole country, a single county were taken. For example, the State of Illinois, with more than one hundred counties, has but three weather bureau stations actually within its limits. The meteorological data for these stations are totally inadequate for the purpose in view. It is therefore believed that the subject might be much more satisfactorily investigated by taking the county in which the Weather Bureau station is located and making the comparisons. I am trying to introduce this system so that thereby it may be possible to make some forecast as to yield. It is now a great question with this country as to the yield of the corn crop of the present year, owing to the prevalence of the recent hot winds over some of the principal corn States of the northwest. This is a great problem, and if we can accomplish its solution it will be of great help to the farmers of the country by giving them the most impartial information obtainable as to actual yields, and this was the idea I had in view in including the matter in the list of subjects for discussion at this convention.

Mr. **Pague** (Oregon). This is a line of work that will lead to a more thorough study of climatic conditions and crop productions. At the present time we have no authentic, rather no thorough, census of crop productions from year to year. Provision should be made to collect crop statistics as thoroughly as we collect climatic data, and not until then can reliable work be done in this direction. Many years ago I endeavored to deduce the relation that existed between the rainfall and wheat production in California, but owing to lack of data the study could not be made as thorough as was desired. Sufficient was deduced to show that the cereal crop of California depended more upon the rainfall of April and May than upon any other factor and that the increased rainfall in these months made increased total production. In Oregon we have no crop statistics, except those in census years. The lack of such important data seriously retards the practical application of data in hand to the future crop products. The prosperity of our nation depends upon the success of the agricultural classes, and the valuable crop forecasts that could be issued on the data that should be extant would be appreciated by all classes of people and by none more so than the farmers.

Mr. **Jennings** (Kansas). I consider this subject one of vital importance to the agriculturists of the country. From investigation of records in Kansas covering twenty-five to forty years I have found that every seven years that country is subjected to drought. According to this theory I believed that the season of 1894 would be one of deficient moisture, and at the beginning thereof advised farmers to plow their "trash" under instead of burning it, as is the general custom. This had the effect of retaining the moisture in the ground, and notwithstanding the marked deficiency in rainfall in Kansas up to last Saturday (August 11), corn was in good condition. Last Saturday the temperature rose to 104°, and this high temperature, with the effects of the protracted drought, had the effect of whitening the blades, but did not materially injure the grain, while in those sections where farmers either had not the advantage of the director's advice or failed to heed it, the prospects for corn are less favorable. From the study of the records I was satisfied that there would be a deficiency in rainfall during the crop season of 1894, and those who heeded my advice as to plowing under the "trash," rather than burning it, did so to their profit.

TOPIC No. 2.

Mr. **TOWNSEND** (Pennsylvania). If the daily papers are relied upon as the principal means of dissemination of crop information there can be but little difference either for or against any day, but if the weekly paper affords the best means of dissemination, then Tuesday is the best day on which to issue the bulletin. In Pennsylvania beyond doubt Tuesday is the best day upon which to publish the bulletin. I think, however, that if the bulletins are issued once in two weeks all interests will be as well served as under the present system.

Mr. **McGANN** (New Jersey). The day of issue of the weather crop bulletin is of vast moment to the respective State weather services, and should be so fixed as to secure its publication in the largest possible number of weekly papers. Since the change from Saturday to Tuesday was made I have found that some weekly papers have been unable to use the information, but upon the whole I agree with Mr. Townsend that it is best to publish the bulletin on Tuesday. The edition of New Jersey weather bulletin is 2,200 copies; it is received from the printer at 2 p. m. and by 4 p. m. the whole edition is in the mails. The plan of publishing notes from correspondents is, in my opinion, the best that could be adopted, as readers of the bulletin like to be informed as to the correspondent furnishing the report; besides, it is a source of compensation to the correspondent to have due credit given him publicly for his report. I believe that other State services should make this plan of giving the correspondent's notes and publishing their names a prominent feature, as is being done in New Jersey. [Mr McGann here cited several instances where the information contained in State bulletins had been used to the pecuniary advantage of the farmer, and also read from communications received from the director of the New Jersey Agricultural Experiment Station attesting the value of the State weather service, especially the weather crop feature.]

Mr. **KERKAM** (Louisiana). In Louisiana the daily papers have given such extensive circulation to the crop bulletin as to make its circulation in the weekly papers of minor importance. I have, however, found that nearly all weekly papers in the State can get the bulletin as published on Tuesday in time for publication. I favor the use of the milliograph in furnishing the press with copies of the bulletin for publication, as by this means it can be more promptly issued and is more readily accepted as news matter by newspapers which, as a rule, care little for matter that has been put into type outside their own offices.

Major **DUNWOODY**. Even though the bulletin should be printed at every central station, a special summary might be prepared for the press, covering the more important features of the weather crop conditions of the week.

Mr. **Berry.** The question of the day of issue of the National and State bulletins is one that has received careful consideration on the part of the Chief of the Weather Bureau, who, after thoroughly looking into the matter and weighing the various interests concerned, has decided that Tuesday, upon the whole, is the best day on which to issue them. It is true, however, that there are some very important agricultural journals that will not publish the bulletins; but this will be the case, no matter on what day the bulletin might be published. It is my opinion that Tuesday is the day on which the bulletin should be continued to be issued in order to give the public the greatest possible benefit.

Mr. **Jennings** (Kansas). The Kellogg Newspaper Company, of Kansas City, prints the Kansas crop bulletin in 500 "patent" sheet papers supplied by them; no other day will suit so well for this work in Kansas as Tuesday. The reports from weather crop correspondents, which begin to arrive Monday, are closely scanned and the special features charted on maps that they may be more easily summarized and discussed. As to improving the character of the State bulletin, the publication of remarks of correspondents is no doubt the best plan, but it is not practicable at present in Kansas, as no means of printing are available. Files of the printed bulletins of other States are being collected to show their superiority over the milliograph, with a view to procuring means of printing. Five to eight stencils are necessary for a single issue.

Mr. **Townsend** (Pennsylvania). It is very important that all State bulletins should be issued at the same time, but the interval between the issues might be lengthened. This would avoid the repetition of much that is now told over and over in the weekly issues.

Mr. **Pague** (Oregon). I do not favor increasing the interval between the issues. In Oregon hot winds sometimes prevail which in a very short time have most decided effect upon the crop outlook. In western Oregon the crops never fail, but in eastern Oregon the hot winds that are liable to occur sometimes reduce excellent wheat prospects to such condition that in sections its only value is that of straw. The printing of notes from crop correspondents is a good plan, but it is impracticable to print them in full in each issue. A good plan is to select certain reports for publication one week and others the next, going through the whole list during the season. The crop telegram to Washington Monday night is filed and summaries given to Associated Press and to newspapers, but it is not generally published by the press until Tuesday. By distributing judiciously to the different points, it is arranged so as to reach all papers at about the same time, by mailing to the more distant points first. The bulletins should be made so brief as not to tax the space of newspapers.

Mr. **Glenn** (South Dakota). In South Dakota a brief summary is preferred to a more detailed report. It is impracticable to give notes from correspondents, there being from some counties as many as twenty-five, when special requests for information are sent to postmasters. Tuesday seems to be the best day on which to issue the bulletin.

Dr. CRONK (Maryland). Though at first favoring the issue of the bulletin later in the week, I now believe the best results follow the issue on Tuesday. Not many farmers take the daily papers, and the weeklies reach a larger number, and it is through the weekly papers that the Maryland bulletins attain greatest circulation. Our bulletin is proofed by noon and mailed by 2.30 p. m. Tuesday.

Mr. HARDINGE (New York). While a majority of the papers in New York are in favor of the issue on Tuesday, they are those of minor importance; the papers with largest circulation prefer Saturday.

Dr. HYATT (Mississippi). Tuesday is without doubt the best day on which to publish the crop bulletin in our State.

Professor SONN (Volunteer Observer). There is a surprising lack of information as to existence of the weather-crop service. If the bulletins were displayed in post-offices the system would become more generally known and prove of greater benefit.

Mr. JENNINGS (Kansas). For the last three years the Kansas bulletin has been placed in at least one post-office in every county, and in some counties in several post-offices. The demand for the Kansas bulletin is such that individuals other than correspondents are not supplied, but the bulletins are displayed in prominent places for the benefit of the public.

Major Dunwoody commended the plan of displaying the bulletin in post-offices. A recent act of Congress provides for more intimate cooperation between the Weather Bureau and the Post-Office Department, and no doubt since the issue of the recent letter of the Postmaster-General concerning the distribution of storm warnings more attention will be paid to the distribution of information emanating from the Bureau.

Mr. McGANN (New Jersey). Good evidence is available of the value of displaying the bulletins in post-offices, and I commend the plan.

Mr. GLENN (South Dakota). The "patent-sheet" newspapers afford excellent means of publishing weather crop information.

Dr. CRONK (Maryland). Bulletins printed on both sides are unsatisfactory for purposes of display.

Mr. McGANN (New Jersey). In reply to objection of displaying bulletins printed on both sides, I would say this difficulty is met by posting two copies.

TOPIC NO. 3.

Mr. KERKAM (Louisiana). I use nothing but actual daily rainfall normals for each day in the year and have computed such normals for every station in the State having records of sufficient length. These normals are bound in book form for convenient reference, from which the dry and rainy periods may be readily seen. The rainfall in Louisiana varies largely, being very heavy in the southern portion, but the northern part of the State is subjected to periods of dry weather. I find these normals of great value in the preparation of frost predictions. [He cited an instance where a study of the average minimum temperature prompted the issue of frost warnings that were verified and that proved of great value.]

Mr. McGANN (New Jersey). The rainfall normals computed from the records of the New Jersey weather service are of the greatest importance. Some scientists have predicted that portions of New Jersey would become a desert, basing their calculations upon measurements of rainfall of questionable accuracy. I have prepared these normals for decades, and published statements showing how many decades during the periods covered by the records have excessive or deficient rainfall. These data have been used to excellent advantage by engineers in constructing reservoirs. Had the State weather service been prepared to give this information five or six years ago the city of Newark would have saved hundreds of thousands of dollars in its public works.

TOPIC NO. 4.

Mr. BURKE (Kentucky) presented a communication from Mr. H. L. Ball, his assistant at Louisville, recommending the use of a return postal card in the collection of weather crop reports, the object being to secure greater regularity in the receipt of reports.

Mr. TOWNSEND (Pennsylvania). The crop correspondents of the Pennsylvania service report with sufficient regularity to provide all data necessary for the weather crop bulletin. I do not believe that any change in the present style of Form No. 1053, Meteorological is advisable.

Mr. McGANN (New Jersey). While the present card, Form No. 1053, is satisfactory, the paper should be of better quality.

Mr. JENNINGS (Kansas). Form No. 1053, at present in use, is well suited for the purpose intended, and I do not believe that such a card as suggested by Mr. Ball will prove satisfactory. The quality of paper is inferior, and the card is too wide to pass through the mails without injury. Postmasters should be instructed not to stamp these reports on the side intended for the report, as the postmarks often render the matter reported illegible. As to providing on Form No. 1067 for an expression of opinion from displaymen as to the verification of forecasts, the plan is not satisfactory. Displaymen have been known to report 100 per cent verification for five or six months when such a percentage could not possibly be attained, while others have reported complete failure, when no doubt the forecasts were highly satisfactory. I do not believe that the estimates given are of practical value.

Mr. PAGUE (Oregon). It is of interest to have displaymen note the verification or nonverification of the forecasts and I suggest that where the estimated percentages are unusually high or low, such cases should be investigated and the reasons ascertained for such estimates. I am inclined to think well of the return postal card for the collection of crop reports, as suggested by Mr. Ball, but am in some doubt as to whether it would prove satisfactory. The present style of Form No. 1053 is admirable. The Form No. 1067, Meteorological, used by displaymen, should provide for verification estimates.

Mr. **Townsend** (Pennsylvania). It will be well to have the card Form No. 1067 provide for such statements as "Good," "Fair," "Bad," but it is not advisable to attempt to give percentages.

Mr. **Kerkam** (Louisiana). The reports of voluntary observers may be used in determining the accuracy of verifications as given by displaymen. If the latter are kindly requested to note verifications they would comply.

Dr. **Cronk** (Maryland). The present Form No. 1053 is satisfactory.

Mr. **Glenn** (South Dakota). The crop report form is too wide for convenient handling in the mails, the forms being frequently broken on the edges. It is important that correspondents sign their reports. I have adopted the plan of thanking correspondents for reports of exceptional worth, notifying them by postal card when reports are received too late for current work, and call upon delinquents to resume reporting. Additional duties should not be imposed upon forecast displaymen, and therefore I do not favor requesting them to give percentages of verification.

Mr. **Jennings** (Kansas). I do not call upon delinquent crop correspondents to resume reporting, but drop their names from the mailing list for the bulletin. When the bulletins are discontinued they quickly ask that their names be restored to the mailing list, and I advise them that the conditions upon which the bulletins can be had is that they contribute reports, and they usually comply.

Mr. **Pague** (Oregon). In order to insure identification of reports, in case of failure to sign, the name of the county is stamped on each card form before distribution. This enables me to determine in nearly every instance who the reporter is, or at least the county from whence the card came, in case of failure to sign.

Mr. **Hardinge** (New York). I favor the present Form No. 1053, except as to quality of paper, which should be better. I do not favor providing a column for percentages of verification on Form No. 1067.

Dr. **Hyatt** (Mississippi). It is advisable to have displaymen give estimates as to verification of forecasts.

Professor **Sonn**, voluntary observer and display man at Newark, N.J., made some excellent remarks relative to the duties and cooperation of voluntary observers and displaymen, stating that it was his custom to keep record of both forecast and the weather conditions following, in order that he might be able to answer criticism. Professor Sonn's remarks as to the exactions on the part of the public, with reference to the fulfillment of the forecasts, were both amusing and interesting, and evinced a keen interest on his part in the work of the Weather Bureau. He found numerous instances of unfair criticism of the Weather Bureau's forecasts, especially with reference to local rains in summer, stating that many people would not admit that such forecasts were justified unless it actually rained upon their hats. At the conclusion of Professor Soun's interesting remarks he was personally thanked by the president in behalf of the association. This concluded the morning session (1 p. m.), and a recess was taken until 2 p. m., when the work of the convention was resumed.

TOPIC NO. 5.

Mr. **BURKE** (Kentucky). I am opposed to the plan of publishing monthly reports of State weather services containing advertisements upon which the support of the publication is to be derived. The time required for soliciting advertisements and keeping proper account of the receipts and expenditures can be illy spared by the officials in charge. Such enterprises are usually conducted at personal sacrifice, having myself lost $50 on the first attempt to publish the report of the Kentucky service by this plan. I find that opposition on the part of the agricultural press is engendered by such undertaking, one editor having stated that he considered it undignified on the part of Government officials to solicit patronage for such a publication. Soliciting advertisements and subscriptions tends to impair the official standing of the representative of the Bureau.

Mr. **CLARKE** (Arkansas). I have tried the experiment of raising funds by advertisements and subscriptions, but without success, owing to the depressed financial conditions prevailing. I agree with Mr. Burke that there are features of this plan decidedly objectionable, as lowering the standing of the Bureau's officials.

Mr. **PAGUE** (Oregon). I recognize the objectionable features referred to by Messrs. Burke and Clarke; still, I believe that such means are justifiable where no provision for publication is made by the State. Although the Oregon report is now published at the expense of the State, it was published at one time by an arrangement somewhat similar to the plan referred to as objectionable.

Major **DUNWOODY** agreed substantially with Mr. Pague as to the plan of publishing reports in those States where no support had been provided.

Mr. **CLARKE** (Arkansas). With reference to the question of publication of daily temperature readings and measurements of rainfall, I think that the National Bureau might supply record books for these data. I also favor graphic illustrations in presenting the meteorological data wherever practicable.

Mr. **PAGUE** (Oregon) enumerated the great advantage of presenting meteorological conditions in graphic form. The excellent charts accompanying the reports of the New York meteorological service made him envious, and he had endeavored to adopt a similar plan in Oregon.

Upon inquiry by Mr. McGann (New Jersey), Mr. Hardinge (New York) stated that the cost of each edition (about 800) of the New York report cost $28.50. The question of cost of meteorological charts was discussed, and it was found that the expense for creditable charts was greater than most of the State services could bear.

As to shading of rain charts, Mr. Berry favored the adoption of the scale of shades used in the Monthly Weather Review. By this scale the shading increases with the amount of rainfall reported, so that the region of heavy and light precipitation may be seen at a glance.

TOPIC No. 6.

At the request of the president, a sample logotype printing outfit, such as is used in printing the forecast messages, was exhibited by Mr. Berry, and its use was explained to those not already familiar with the system.

Mr. McGANN (New Jersey). It is desirable to lengthen, if possible, the period covered by the forecasts. If the forecasts could be made for forty-eight hours it would be possible to reach by mail a largely increased number of places that it is now impossible to serve until so much of the time covered by the forecast has lapsed that the information proves of little value.

Mr. TOWNSEND (Pennsylvania). I agree with Mr. McGann as to the necessity of predictions of long range and believe that such forecasts might be made by the officials of the Weather Bureau, who are in position to know better than the public what weather conditions might reasonably be expected to prevail forty-eight hours in advance. The percentage of verification that might result from lengthening the period would be more than compensated for by the value of the successful predictions.

Mr. CLARKE (Arkansas). There are but few points in my State that do not receive the thirty-six-hour forecasts made in the morning almost as soon as issued, and the stations receiving them latest have at least thirty hours of the period unexpired by time of receipt.

Major DUNWOODY. To extend the period covered by the forecasts beyond thirty-six hours would, as a rule, render the predictions mere guesswork.

Mr. TOWNSEND said there was a disposition on the part of the press to publish long-range forecasts, such as published in the New York Herald.

Major DUNWOODY stated that he believed that interest in such forecasts would die out.

Mr. TOWNSEND thought that it would be well for the Bureau to take the matter of long-range forecasts under consideration.

The logotype system for the distribution of forecasts by mail was considered by all State-service officials present to be the most economical and effective plan that has yet been tried for the dissemination of weather information. With reference to the present plan of telegraphing the forecasts only when decided precipitation or decided temperature changes are expected, it was the opinion of all present that the system was objectionable and that the Bureau should return to the former plan of sending the forecasts daily.

Mr. TOWNSEND said that it was difficult to make the public understand the conditions upon which the forecasts are sent, and that messages should be sent daily. Messrs. McGann, Hardinge, Cronk, Hyatt, Pague, and Smith (local forecast official, Boston) agreed with Mr. Townsend that the messages should be sent daily.

Mr. JENNINGS. In Kansas the present plan receives no praise and much unfavorable criticism. The only thing in its favor is its economical feature, but the loss to the Bureau for less efficient service is great. The plan necessitates much explanation, and the unfavorable criticisms can only be successfully met by the statement that the Government by this plan can supply a greater number of places with the forecasts than would be possible otherwise.

Among other objections to the present plan, Mr. Clarke referred to the gradual rises in temperature from day to day, by which marked extremes might occur with no forecasts from the Weather Bureau.

Mr. GLENN. The infrequency of the telegrams cause displaymen to be indifferent in making the displays and rendering correct monthly reports. An objection to the plan is the uncertainty to which specially interested persons are subjected by the absence of a telegram indicating fair weather and stationary temperature, when very important and valuable weather information can be long delayed in transmission by broken, crossed, or grounded wires, an open key, or the indifference of an operator, and the occasion of the delay not be known to the general public. In South Dakota it was of the greatest importance that daily forecasts should be telegraphed, as lack of such information in winter might sometimes result in loss of life.

Messrs. Townsend, Hardinge, and Jennings spoke of delays in delivering messages resulting from unsatisfactory telegraphic service, Mr. Hardinge stating that investigation of such delays had always resulted in improved service. With reference to the question whether the present system of flag signals should be continued, while Messrs. Townsend and McGann were of the opinion that the objections to flags were such as to justify their discontinuance, Messrs. Hyatt, Clarke, Glenn, Hardinge, Jennings, and Berry were in favor of continuing the flag system. Mr. McGann stated that he found that displaymen were inclined to neglect changing the flags and that the bad effects of having flags flying that did not represent the official forecasts were such as to persuade him that flag displays should be abandoned and the logotype system extended.

Mr. Burke was also of the opinion that the logotype bulletins afforded a more satisfactory means of dissemination.

Mr. Glenn. The flag system is satisfactory in South Dakota, but a flag might be designed that would serve to indicate both temperature and weather in a single display, doing away with the present temperature flag. The scarcity of lumber renders the securing of a good flagstaff difficult and expensive, and as buildings are generally low, the size of the flag might be reduced with advantage.

Mr. Pague. I would dislike very much to see the flag system dispensed with. The system is popular throughout the Pacific Coast and especially in the raisin districts of California. The logotype plan is good, but it fails to serve purposes that are fully met by the flags.

Mr. Clarke. The flags have so long successfully been employed by the Weather Bureau as a means of communicating information that I hope that their use will be continued.

Mr. Berry. I favor flags, and while admitting that the system is defective, it possesses many merits, and I believe that it could not be dispensed with without impairing the usefulness of the Bureau. The flags should be continued and the logotype system extended. With both these popular means of dissemination the Bureau can do a great deal more than with either alone.

Mr. McGann. The definitions of the flags are not generally known and people will not take the pains to inform themselves as to their meaning, but with the logotype bulletin each person can read the message, and this is more satisfactory.

Mr. Glenn. Some of the most zealous displaymen in South Dakota are sometimes remiss in the matter of rendering reports of displays; and the enforcement of the rule requiring the cutting off of telegraphic service unless reports of displays were rendered, in some instances, resulted in the loss of their cooperation, much to my regret. I am in favor of allowing the telegrams for the purpose of bulletin displays where flag displaymen are not available, except in the larger towns.

Mr. McGann. It is my experience in New Jersey that it is not a desirable plan to have one person act in the capacity of voluntary observer, displayman, and crop correspondent, and I advise that different persons be secured to act in the several capacities.

Referring to night signals, Mr. Townsend said that the short distance which these signals could be seen would render such system faulty; the proper appliances would prove too expensive to render such a plan feasible.

Mr. Jennings also thought that the expense of night signals would be too great to make any system that might be tried practicable.

Mr. Glenn. I regard the question of long-distance signals as one of much importance to the Weather Bureau. On the plains the light from extensive prairie fires can be seen a distance of about 90 miles, and if some effective means of communicating forecasts by means of night signals can be devised it would doubtless prove of great benefit in my State. I have given considerable thought to this question, considering the use of bombs, rockets, etc., and think that it would be well for the National Bureau to conduct some experiments in this line. The Weather Bureau observer at Pierre, S. Dak., is very favorably situated for testing any such system.

Mr. **JENNINGS.** So far as distance at which the lights might be seen is concerned, electric lights may be seen 20 to 25 miles distant from an observer, and objects may be seen in daytime 30 or 35 miles away, so that there can be no doubt, if proper appliances could be had at an expense that would not be too great, such signals would be the means of making known the forecasts over a wide extent of territory.

Major **DUNWOODY.** From experiments made in Pennsylvania, at Williams Grove and Mechanicsburg, with lights and rockets, the farmers were favorably impressed with the system. The Weather Bureau officials at Pierre or Huron might be able to do effective work in the way of announcing cold waves.

Mr. **GLENN.** In my opinion long-distance night signals should be used only for cold wave and storm warnings, and not for the ordinary daily forecasts.

Mr. **PAGUE.** There are instances where the forecasts had been displayed by stereopticon lights on the stages of theaters with good effect, and I believe the plan to be very good. Of course such a system could only be used in the populous cities. Experiments had been made with flash lights between Mount Hood and Portland, Oreg., a distance of 70 miles, but the light was of insufficient power to prove effective. If a plan of night signals could be put into successful operation at Mount Hood it would give 150,000 people the benefit of the forecasts. On account of the difference between Pacific Coast and Eastern time it is possible to give the forecasts based upon the 8 p. m. (75th meridian time) observations distribution on the Pacific Coast at an hour sufficiently early to make the forecasts of much greater value than would be possible if distributed two or three hours later (local time), as is the case east of the Mississippi River.

TOPIC No. 7.

Mr. **CLARKE.** I have spoken at farmers' conventions of the great need for the inspection of voluntary stations, and long recognized that such inspections are of the first importance; and after having succeeded in providing the necessary means, the general authority was cut off by the central office of the National Bureau, so that the trips could not be made without a specially granted authority for the necessary absence in each case. [As evidence of the necessity for the inspections, Mr. Clarke cited cases in which it had been found that the maximum thermometers in use were acting as ordinary exposed thermometers, thereby giving erroneous records.] Until the officials were given the general authority that they formerly had, these inspections could not be advantageously made.

Mr. McGann. It is of the utmost importance that inspections be made, and it will not only be necessary to restore the former general authority for the necessary absences, but the time should be extended to cover three days; the former authority allowed two days. It is a pleasant duty to meet the voluntary observers of the State service, who are among the best classes of people, and acquaint them in their work.

Mr. Jennings. A personal inspection of voluntary stations brings the directors and observers nearer together and arouses greater interest in the work. I find that observers welcome the visits of the director for the purpose of inspection. There being very few instrument shelters in use in Kansas, inspections become the more important, that the best exposures possible without shelters may be secured. [He cited a case where the readings of the minimum thermometer were made at the wrong end of the index.] Such errors are liable to occur with persons who under proper instruction from personal inspection become the most efficient observers. Months of correspondence often fails to accomplish what can readily be effected by personal interview.

Mr. Glenn. I agree with Mr. Jennings in what he said with reference to inspections. In South Dakota some of the most indifferent observers have, as a result of personal instruction, become the most efficient. Owing to distances and difficulties in travel, the time limit for inspections should be increased to four days.

Mr. Townsend. It is of the utmost importance that voluntary observation stations be inspected for the purpose of remedying defects in instruments. Air specks in thermometers prove troublesome and are easily removed by an experienced person, but many instruments are broken by inexperienced persons in their efforts to correct such defects. I found in one case a maximum thermometer suspended after the manner of the ordinary exposed thermometer.

Mr. Pague. I have at former conventions urged the importance of inspecting voluntary stations for the purpose of forming the acquaintance of observers and giving them instruction. These inspections bring the colaborers in State service into close, harmonious relations, and, to secure best results, should be made annually. An annual inspection of stations will do more to develop our work than any other means can possibly accomplish.

Topic No. 8.

Mr. Jennings. The present outfit, consisting of a set of maximum and minimum thermometers and a rain gauge, is satisfactory. A more extensive outfit would be inadvisable, at least at the present time, in view of the difficulties met in securing the best results possible with the present outfit.

Dr. Cronk. The outfit mentioned by Mr. Jennings is ample.

Mr. **Townsend**. Efforts to secure humidity observations in Pennsylvania have been unsuccessful, and nothing other than a suitable instrument shelter should be added to the observer's present equipment, viz, maximum and minimum thermometers and rain gauge.

Mr. **McGann**. I consider wind vanes as necessary, and I shall endeavor to provide New Jersey observers with them.

Mr. Townsend asked an expression as to the hours of observation.

Mr. Jennings stated the Kansas observers were requested to take their observations at 7 p. m. "railroad time," corresponding to the 8 p. m. 75th-meridian time.

Mr. Hardinge stated that the New York observers were instructed to take their observations about sunset, no more definite hour being fixed.

There being no further remarks, and the programme of subjects having been gone through with, the president stated that he would be pleased to have the directors present relate their experiences with reference to efforts made to secure State or local aid in carrying on the work of their respective services.

Mr. **Townsend**. Pennsylvania has appropriated $6,000 for the work of the weather service in that State. This sum is used in the purchase of instruments for observers, printing the reports, and employment of an assistant. Several years ago the State had made an appropriation of $5,000, then there was an interval when no support was furnished. The disbursements are made by the secretary of internal affairs. The meteorological committee of the Franklin Institute has charge of the service, and under them the assistant director carries on the work. The local service is well and popularly known throughout the State. The crop bulletins are printed; and as the widest circulation of the information they contain is to be had through the press, my efforts are mainly in that direction rather than by individual distribution.

Mr. **Hardinge**. The New York State weather bureau is now under the State department of agriculture. An appropriation of $4,500 for its support was made, the disbursements being under the State commissioner. The work of the State service is steadily increasing.

Mr. **Glenn**. The first session of the South Dakota legislature passed a bill creating a State weather bureau, but the appropriation requested for its support ($600) failed of passage. A similar measure failed of passage at the second session on account of the large appropriations made in connection with the State's exhibit at the World's Fair. At present I can not look for State aid. The crop bulletin is a popular feature of the work in South Dakota.

Dr. **Hyatt**. No bill has yet been passed for the support of the Mississippi service. The service is very popular and the excellent work that has been accomplished this year, with the abundant crops, should be favorable to the proposition for State aid.

Mr. **McGann**. The New Jersey service was organized some years ago and an appropriation of $1,000 per annum made for its expenses. For several years I met with defeat in my efforts to secure assistance, but after severing all relations with colleges and scientific institutions, and promising that the State service should be made of practical value, an appropriation of $1,000 was made by the State. In addition, the State board of agriculture provides $100. Within the $1,100 the expenses of the service are confined.

Mr. JENNINGS. Owing to complicated political conditions existing in Kansas, no State aid has been secured, and the local service relies entirely upon the National Bureau, and with the support received is able to accomplish valuable work. Monthly meteorological reports are issued by the mifliograph process, but the State board of agriculture publishes the report in printed form quarterly. The railroads make extensive use of the meteorological data in publishing among immigrants the climatic features of the State.

Dr. Cronk explained the conditions under which the service in Maryland is operated. The legislature having provided an annual appropriation of $2,000 for its support, the Governor would not approve the act without assurance that but one-half the sum appropriated would be expended. After the service had been in operation one year, however, he withdrew his restriction and permitted the whole sum to be used.

Mr. PAGUE (Oregon). The Oregon service was organized by myself in 1886, the first monthly reports appearing in the Commercial News, published in the city of Portland, during the autumn of 1887; in 1888 a paper was started which was devoted entirely to the work of the service. Through circumstances the work was discontinued with the August, 1888, issue. The Oregon legislature, at its session in February, 1889, passed a bill creating the State weather service and making an appropriation of $2,000 for the same. By a constitutional provision the State printer is required to print all reports, blanks, etc., for State officers, hence the printing for the service does not come out of the appropriation. At subsequent meetings of the legislature aid has been continued to the service. The service is well known and popular in the State. The people rely upon it for climatic, crop, and other statistics. The press of the State recognize its value and importance. I am proud of the Oregon service, a creature of my own making; a valuable adjunct to our National Bureau; a much prized, respected, and useful organization to the people of my State. We have the cordial support of all colleges and scientific associations, the farmers' organizations, the good will and assistance of the business and public men of the State.

The following papers submitted by absent directors were presented and read:

IRRIGATION AND ITS RELATION TO STATE WEATHER SERVICE WORK.

In this crop season, when in the great central States of the Mississippi Valley long-continued and unexampled droughts have parched and ruined once promising crops; when stock has died for lack of water; when destruction has been widespread, and many farmers have been ruined in fortune, how natural it is to wish that it all could have been avoided; that in some way the adverse elements could have been controlled.

To look for help in such a case from the so-called "rain-makers" is vain, for, even conceding the entirely unproved, undemonstrated claim that they can "make" artificial rain, or, in other words, cause rain to fall where it would otherwise not have fallen, it is sure that in "producing" for one locality they would take away a portion of what rightfully would belong to another.

What more natural than for the mind to turn from such scenes of crop destruction and desolation as the past two months have witnessed in the fertile Mississippi Valley to lands where rain failure in the growing months, though it may cause discomfort and perhaps loss, can not cause widespread disaster. How natural to think of those irrigated districts where the waters of never-failing rivers or inexhaustible lakes are turned into canals and smaller and ever-branching ditches to water the thirsty soil, even as from the large arteries of our bodies branch the ever-ramifying blood vessels to the smallest capillaries to carry food for our wasted tissues. And the thought is suggested, Why, even in our great Mississippi Valley, where harvest is always almost certain, should not the waters of the ever-flowing streams be diverted out over the land to insure certain crops rather than run fruitless toward the sea?

The irrigation idea is not one of the brilliant inventions of the nineteenth century. It almost appears to be coeval with the dawn of agriculture on the planet. Far back beyond authentic history, in Egypt, Assyria, and Mesopotamia immense canals bore water over land much of which is now a desert; in Arizona, and elsewhere on this continent, explorers have found ruins of irrigating canals and reservoirs, which would indicate that long before the discovery of America a civilized people carried on agriculture by irrigation on an immense scale, in comparison with which the irrigation revived but a comparatively short time ago in Utah and other far western States is on a small scale.

Forty-seven years ago the pioneers in Utah (pioneers indeed west of the Missouri) trained the waters of the mountain torrents over a tract of sage-brush desert, imitating the fathers of primeval times. Their success was beyond expectation, and their example in converting a desert into fruitful fields by the use of flowing water was followed by other localities of the arid region, until once barren California has become a land of flowers, blooming orchards, and waving grain, while the neighboring States are little less. What though no rain falls during summer, or scarcely any? The mountain peaks collect the snows of winter, and from them flow the copious streams which, led out over the farms, insure certain production. Possibilities remain of great reservoirs and canals which may reclaim vast areas of land. In 1891 the total acreage covered by ditches was 735,226 acres. The total irrigable land was 2,304,000 acres, leaving an additional acreage susceptible of irrigation of 1,568,774 acres. In other of the arid States or Territories I know not what the ratio is, but would judge it to be much greater in favor of irrigable lands not covered by ditches. Should the bill now pending in Congress become a law the unoccupied arid lands will be ceded to the various States in whose confines they are for purposes of development by irrigation.

The State which would fail to develop its irrigation possibilities and reclaim its arid lands would be making a very grave mistake.

But besides in the arid region I would advocate irrigation in all States, although they were considered fertile, where great droughts are of frequent occurrence or even possible. Even where rain never fails, if irrigation were employed it would probably so greatly increase the productions of the locality as to well pay for the cost, but I think that irrigation in regions where droughts occur is positively imperative, and, so far as can be seen, does not present great difficulties. In Minnesota, Wisconsin, Iowa, Illinois, Missouri, are countless lakes and rivers, while the

Dakotas, Nebraska, and Kansas are not poorly supplied. The slope of the country is everywhere sufficient to make a system of flowing ditches possible. The legal difficulties are not insuperable; rights of way could easily be obtained for water rights; the canals could often be constructed along the public highways. To be sure, methods of farming would change as a result. The farmer now working 80 acres alone could not irrigate more than 20; but his increased productions would many fold pay for the additional help required. Thus the production of our great central States might be increased beyond computation. As the time will surely come when an overflowing population will make all this a necessity, it were better, it seems to me, that the beginning were made now.

The province of the State weather service in this is, I think, that of advocacy and furnishing information. An opportunity should not be missed in State weather service publications of showing what irrigation does, has done, and can do. It is the meteorologist alone who can tell what amount of rainfall can be depended upon to give the water supply for any region. He it is who may reasonably be called upon by the irrigation engineer to furnish the primary data. The weather service of a State should have sufficient available data to enable the water supply of any of its drainage areas to be computed. It should also be able to give adequate figures on temperature and evaporation; soil absorption, too, might also be within its province. For all this, as many well-selected observing stations as are possible are necessary. They should be well distributed along watersheds and the smaller tributaries of the streams, and in mountainous States as far up among the mountains as people live. Snowfall measurements should be made, even at some expense, high up where the streams head among the snow fields.

Is it objected that this is beyond the province of the State weather service? I maintain that none but the experienced, trained, and well-informed meteorologist can properly conduct such work; no one so well understands what an inch of rainfall or a foot of snow means; no one is so well fitted to work up the collected data into totals and normals; no one can so judiciously select and classify the stations. It should, therefore, be State weather service work, and paid for by the State where the State is able, otherwise by the national service.

Three years ago the first irrigation congress of the States of the arid region was held at Salt Lake City, which memorialized Congress to grant the unoccupied public lands to the States in severalty, in trust for the purpose of developing irrigation. Since then annual congresses have been held; the idea has taken root, and is growing; irrigation will yet be, as our crop reporters have frequently stated it to be in Utah, "the order of the day."

With irrigation meteorology is inseparably bound. The original source of all our lakes and streams is precipitation in the form of rain or snow. This is the original water supply. The guarantee to the irrigation engineer of a sufficient and constant water supply is the information furnished by the meteorologist. Such information can best be collected by State weather services. I do not think that the collection and dissemination of such data necessarily conflicts with the work of the irrigation division of this Department, any more than the crop information of our bulletins conflicts with the work of the statistical division. The work of one division merely supplements that of the other.

It is a legitimate aim of the State weather services to ascertain definitely the amount of rainfall that occurs in our several States and Territories and the maximum amount of it that can be rendered available for purposes of agriculture. Should irrigation projects, based on the information collected by the State weather services, succeed in reclaiming a vast amount of hitherto valueless land, and make crops a certain success in regions where now possible droughts render them precarious and uncertain, all the money, time, and thought the services have cost will have been expended to the best advantage.

GEORGE N. SALISBURY,
Observer Weather Bureau, Director Utah Weather Service.

The following paper dealing with the characteristics of Utah in their relation to State weather service work was written by Mr. Salisbury:

CHARACTERISTICS OF UTAH IN RELATION TO STATE WEATHER SERVICE WORK.

Utah! What varied conceptions arise in your minds as this word is read—no two alike, I venture to say, no matter how well versed you may be in its geography, climate, topography, or its history. And this is natural, for all ideas must vary with the point of view. Utah's winters seem mild to the inhabitants of Minnesota and the Dakotas, though they would be extremely rigorous to the natives of Florida or the Carolinas; and our summers with burning sun are yet very comfortable to those accustomed to the sweltering hot months of the Atlantic coast States.

Of its geography, though one may know well the boundaries of the now embryonic State (just hatching from its shell), and be familiar with the location of Great Salt Lake, Ogden, and the Jordan River, yet he may know absolutely nothing of the local geography, of its diversified mountain chains, its hundreds of beautiful valleys, its mighty mountain-walled rivers, its vast deserts and rugged peaks, its forests of pine, fir, and aspen, its mountain snow fields and mirrored lakes, with a thousand sparkling torrents dashing headlong over granite rocks and through tangled copses to be turned through ditches into chosen paths to water and fertilize the valleys, to at last sink in the sands of the desert or lose themselves in the brine of Great Salt Lake and again arise to the sky from its surface. Of its fruitful fields, many, though small, he has little conception unless he has traveled among them. Its history—ah, that is more or less known to all; but charity will not rudely tear aside the veil that kind oblivion is weaving. History, too, varies with the point of view; to the pioneers of Utah their record is all glorious, whatever it may be to others, while the newcomers fancy that they themselves have done all that has been worthily done in the Territory of temples, tabernacles, and presidents. I dwell so at length on this introduction merely to show how different things seem from different standpoints—how different Utah is to the Utah man from what it is to the Eastern man; and doubtless it is the same way in other States.

Utah's well-known unbounded wealth in the metals has made it appear to many exclusively a mineral region, and so it is to the miner. Those who know of its immense mountain pastures, great herds of cattle, and flocks of sheep, think it pre-eminently a grazing country. Truly, from the standpoint of the cattle and sheep men, Utah is a grazing region.

But to the tillers of the soil—who have so patiently grubbed out the sage brush, dammed the mountain torrents, constructed reservoirs, trained their ditches over the fields, built flood gates, and wasteweirs, and service gates, broken the soil, planted orchards and fields, and never failed to harvest some bountiful crop, if only of the plain and unprepossessing potato—it is a paradise of the agriculturist.

It is with agriculture that State weather services have had most to do, although too exclusively, I am inclined to believe. Climate affects all interests, industries, and occupations to a greater or less degree, and although agriculture may be entitled to receive more attention from the State weather service than other persuits, any possible benefits to the others should not be lost sight of.

Of all the pursuits mining may be justly considered as the one which takes the least interest in climatic work, and as the one hardest to reach with any benefits of the service, notwithstanding its water supply (an essential) is entirely dependent upon climate, and the periods during which development may be profitably done, and ore hauled, can be determined from climatic statistics. The search for the alluring metal is too absorbing to permit of such secondary considerations.

The climatic service in Utah has been principally utilized by agricultural, sanitary, and advertising interests. Of late, however, the accurate details of the service have not been glowing enough for the uses of the railroad pamphlets and the various circulars advertising Utah, but, for reasons best known to themselves or readily suspected by a weather investigator, they have preferred to use those glittering generalities about climate which allure without betraying. According to my thinking, however, Utah has nothing that need be concealed in the matter of climate, and tourists and settlers would be more attracted and sanitariums sooner built up at our hot springs and resorts by publishing to the world the exact facts.

Utah has, as regards temperature, four distinct regions: First, the valleys on the eastern side of Great Salt Lake, with a mean annual temperature of 50° to slightly above; second, the great plateau region of the central and western parts, with an annual mean below 50°; third, the extreme north of the Territory, with annual mean of 40 to 45°; and, fourth, the extreme southwest portion, with annual mean of 50 to 60°. At St. George, in the latter region, the summer temperature sometimes reaches as high as 118° on the hottest day. On very few winter days does the temperature fall below the freezing point, and never below zero.

These divisions of climate are due to the combined effect of latitude, storm direction, and topography. The latter is somewhat peculiar. The Wasatch Mountains, extending to a height of 8,000 feet above the general surface of the plateau, with parallel ranges and many lateral spurs, traverse the Territory from north to south, while the Uintah range, still higher, in the northern part of the Territory, forms a connecting link between the Wasatch chain and the main divide of the Rocky Mountains. The deserts in the western third of the Territory and the principal mountain valleys are 4,000 to 6,000 feet above the sea. The valleys in the extreme southwest are less in elevation, being 2,000 to 3,000 feet above sea level.

Omitting the small streams flowing into Bear Lake, there are but two river systems—those going into the Colorado and those tributary to the great evaporating lakes. All have their sources in the snow fields of the mountains. The streams flowing into the Colorado run, for the most part, in what are known as box canyons, from hundreds to thousands of feet below the general surface, and, therefore, little of them can be utilized in reclaiming that vast area of arid land east of the Wasatch chain. The rivers and mountain streams of the other systems, however, flow through more or less open valleys, and are capable of being utilized to the last drop in watering the soil. The soil is that sort of "gumbo" found beneath sage brush in the Western States, and is of unsurpassed fertility when properly watered. The valleys of lowest elevation produce splendid crops of grain and vegetables, and with proper cultivation the finest quality of such fruits as can endure a winter season are produced.

It is in these valleys, therefore, that the agricultural part of the population (and indeed nearly all of it) live, and so it is with these valleys that the Utah weather service has most to do. For a knowledge of the precipitation of the Territory it is indeed very desirable to ascertain how much rain and snow fall over the desert, and how much, especially of the snows of winter, falls on the mountain peaks; but, manifestly, a volunteer service can not be established where no people live. It is in the valleys, irregular as they are, that stations have to be established. They must be established, if at all, where they can be, and be undertaken by such observers as are willing to give their services gratis. Such men may not be those best fitted in their communities. Usually they are what is termed "weather cranks" by their neighbors, who can see no objective point to any pathway that does not lead directly to a pile of dollars. For only a portion of the population of Utah are, to use a much abused colloquialism, "out there for their health." In the mining towns none are willing to give their time, which to them means money, or such as might are too rough and unintelligent for the purpose. In the cities the professional men, while best fitted for the work of observation, are too busily occupied in chasing the exceedingly nimble and fast-receding dollar.

So, such weather service as there is has collected its corps of voluntary observers by a similar process to what is named by scientists, "natural selection and survival of the fittest." Some, unpromising at first, have become in time very good, and others starting well, soon tired of the work and became inefficient.

The city newspapers have, as a rule, done much to foster the service, while the indifference of the mining interests and the conservatism of a large element of the population have, undoubtedly, had their effects. In overcoming such adverse influences, local pride, and also the personal pride of the observer, have to be appealed to. Time will gradually accustom these communities to the service so that it will appear to them indispensable.

Under such circumstances, and with such materials, the climatic statistics of Utah have been collected. You readily understand how the mountainous character of the country has prevented much railroad and telegraph extension, and how the consequent poor mail and telegraph facilities have hindered both the collection and distribution of data. Nothing done by the service has so taken the popular fancy as the weather crop bulletins. The farmers have delighted to report their crops, and eagerly scan the bulletins. One reporter informed me that several of his neighbors, discouraged by the poor crops of last year, would have moved away, had they not seen by the bulletins that it was a poor year throughout the Territory. The daily papers have given great prominence to the bulletins.

How far, it may be asked, can the Service be advantageously extended in a territory of 84,750 square miles, of which only 750,000 acres are under cultivation? I would advocate that not only the inhabited districts be represented by voluntary observers, but that paid observers be located on the mountains and deserts until the climate shall be well determined. This should properly be done by the State, but if not done by the State it ought to be done by the National Service. With a systematic development of the arid but tillable land yet unirrigated, the extent of the inhabited territory may be doubled, and the Service correspondingly increased.

In this development the Weather Service ought to have an important part in furnishing precipitation data which hydraulic engineers may use to calculate the water tributary to their storage reservoirs or the streams from which their canals are taken.

The distribution of forecasts in a country like Utah, where the farmers regularly water their crops whether it rains or shines, is of less importance than in other countries, and it is difficult to see their utility, except as storm warnings and frost and cold-wave warnings. The grazing industry, however, could be largely benefited by well-timed warnings. There ought to be more security for the immense flocks of sheep and herds of cattle that now graze in the elevated valleys. Warnings of severe storms and cold waves could and should be given two days in advance.

So much for Utah's climate, resources, and possibilities of State weather service work, and yet the half has not been told. Without the spirit of prophecy, one who runs may read that with returning prosperity throughout the country, a career of wonderful development is about to open for Utah. Her mines will be worked to full capacity, railroads will be built, the wheels of industry will turn, her acreage under cultivation will double, great harvests of fruit will yet be produced, her bountiful wheat harvests will continue, her cities become populous, her common schools and educational institutions equal the finest in the land. Thus, out of the desert will arise a great empire State—a bright particular star in the galaxy of States. May it be so, and with such advancement may the Utah weather service keep pace, being ever an important factor in that development.

GEORGE N. SALISBURY,
Utah Weather Service, Salt Lake City, Utah.

Mr. F. P. Chaffee, of Montgomery, Ala., regretted his absence, but discussed to some extent the fifth topic in the following letter to President Dunwoody:

MONTGOMERY, Ala., *August 12, 1894.*

Maj. H. H. C. DUNWOODY,
President American Association of State Weather Services,
Washington, D. C.

SIR: Owing to causes beyond my control, I will be unable to attend the convention of the association to be held at Brooklyn, N. Y., during the present month. While regretting my inability to be present, I must say that the meeting has my hearty sympathy in its work, which, like those of previous meetings of the association, can only result in the improvement of the State weather services of the country, and increasing the benefits derived therefrom.

In reference to the fifth topic for discussion of the third annual convention of the association—"Monthly publication of State weather services: (*a*) Should the publication of monthly reports containing advertisements be encouraged?"—I would submit the following:

As understood by the writer, the only cases in which advertisements appear in such publications is where there has been a demand for such an increase in the publication of the monthly reports as could not be well met with the crude and laborious method of issuing them by the milliograph and similar duplicating processes, and where no State aid is furnished to print the reports.

In such cases the advertisements are a matter of necessity, as they pay for the printing and other expenses incident to the publication.

It is thought that there is hardly a case where the maintenance of such publications has been a matter of profit, and in many such cases, it is thought, they have been of some pecuniary loss to those publishing them.

The advantage of printed publications over milliographed reports is very evident. They present the information in more attractive and more readable shape, admit of a much wider publication, and are a means of creating more interest in the work among the voluntary observers and the general public.

Knowing the advantages of printed publications, it would seem that, should the maintenance of the printed monthly reports by advertisements be discouraged where no State aid can be obtained for such publications, some other means should be provided for printing these reports. With this end in view, I would suggest the following:

That where no State aid is furnished the State weather services, that the monthly reports of such services be printed at the central office of the National Weather Bureau, and a sufficient number of copies of the same be furnished the directors of the State weather services for distribution. The Monthly Weather Review of the National Bureau now publishes a portion of the detailed data of the voluntary reports of the various State weather services. By increasing this, and devoting, say, one page of the Review to the reports of each of the State services, the Monthly Weather Review would be made more complete and more valuable as a statistical publication, and advance sheets of such pages could be printed and forwarded to the various State weather service centers, where they would serve very nicely for monthly reports.

Such a system would not be very expensive, and would entail no great delay in publication, as many of the monthly reports of the State weather services are now published several weeks after the month of which they form a record, and it would have the advantage of insuring quite a uniformity in the reports.

The "copy" for these reports could be made up at the State weather service centers and forwarded to Washington by the 10th of the succeeding month, and could probably be printed and copies returned for distribution as quickly as the reports of many of the State weather services are now published.

I inclose herewith a sample of about how such a report as just suggested should be made up. This might be considerably contracted, by condensing both the summary and the table. The daily temperatures and the daily rainfalls are not given in this sample, as it is not considered necessary, as a record of such data can be kept at the central stations, from which demands for such information can be met.

It is understood that a number of objections might be offered to the method suggested above, but it is mentioned with a view of exciting just such criticism, from which might evolve some better method of printing the monthly reports of the State weather services.

Very respectfully,

F. P. CHAFFEE,
Local Forecast Official, Weather Bureau,
Director Alabama S. W. S.

Upon motion of Mr. Jennings, duly seconded, the constitution[1] was amended as follows:

After section 1, Article II, add: "Provided the President may have power to call the meeting at some other time and place."

OFFICERS OF THE ASSOCIATION.

The election of officers for she ensuing year, as below, concluded the work of the convention:

President, Maj. H. H. C. Dunwoody, U. S. A., assistant chief of Weather Bureau, Washington, D. C.; first vice-president, T. F. Townsend, Weather Bureau, assistant director Pennsylvania weather service, Philadelphia, Pa.; second vice-president, S. W. Glenn, local forecast official, director South Dakota weather service, Huron, S. Dak.; secretary and treasurer, James Berry, chief State weather service division, Weather Bureau, Washington, D. C.; executive committee, Messrs. J. Warren Smith, director New England weather service, Boston, Mass., Mr. E. W. McGann, director, New Jersey weather service, New Brunswick, N. J., and Dr. C. P. Cronk, meteorologist in charge Maryland weather service, Baltimore, Md.

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[1] See First Annual Report, American Association of State Weather Services.

Bulletin No. 15.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

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OF
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PROTECTION FROM LIGHTNING

BY

ALEXANDER McADIE
U. S. WEATHER BUREAU.

WASHINGTON, D. C.:
WEATHER BUREAU.
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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., March 18, 1895.

SIR: I have the honor to transmit herewith a revised copy of the circular of information entitled "Protection from Lightning," and to recommend its publication as a Bulletin of the Weather Bureau.

Very respectfully,

MARK W. HARRINGTON,
Chief of Bureau.

HON. J. STERLING MORTON,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

WASHINGTON, D. C., *March* 11, 1895.

SIR: I have the honor to submit for publication a revised copy of the pamphlet entitled "Protection from Lightning." Upon few subjects is the community so liable to be misled as on that of the best methods of protecting life and property from lightning. The following pages give statistics of actual losses, the theory of protection in language—free from technicalities, and directions for procedure in cases of apparent death from lightning stroke. A collection of practical rules for guidance in selecting and maintaining conductors, and a notable instance in the case of the Washington Monument of the successful use of protectors, are also given.

The aim of the paper is to furnish information of practical value to all classes, and especially to farmers, builders, and physicians.

Very respectfully,

ALEXANDER McADIE.

MARK W. HARRINGTON,
Chief of Weather Bureau.

PROTECTION FROM LIGHTNING.

At the Aberdeen meeting of the British Association for the Advancement of Science Sir William Thomson made the remark, "If I urge Glasgow manufacturers to put up lightning rods they say it is cheaper to insure than to do so."

This was the answer given by practical business men, concerned only with questions of profit and loss, to the foremost physicist of our time; and their answer will serve as fairly representing views widely held, founded upon the double belief that the risk from lightning is not so very great and the protection afforded by the present methods not sufficiently certain to warrant implicit confidence and justify the necessary expense.

The recent remarkable experiments of Dr. Oliver Lodge, in his lectures before the Society of Arts, opposing and to some degree directly contradicting the empirical rules of the Lightning Rod Conference, have given support to the belief that the protection was uncertain. Indeed, realizing that his work might be misinterpreted, Lodge has stated "an idea at one time got abroad that my experiments proved existing lightning conductors to be useless or dangerous; this is an entire misrepresentation. Almost any conductor is probably better than none, but few or no conductors are absolute and complete safeguards. Certain habits of lightning rod practice may be improved and the curious freaks or vagaries of lightning strokes in protected buildings are intelligible without any blame attaching to the conductor; but this is very different from the contention that lightning rods are unnecessary and useless. They are essential to anything like security."[1]

What Lodge's brilliant experimental work does show is that the momentum of an electric current can not be overlooked in a lightning discharge. The old "drain-pipe" idea of conveying electricity gently from cloud to earth must give place to the new proposition, based upon recent discoveries, that even draining off must be done in an appropriate way to be effective. To illustrate, the rocks and trees upon a mountain side may influence and determine the course of a mountain stream, but even a good sized channel would not suffice to carry off safely an avalanche, or control the path of a landslide; so with lightning. In the past four years we have learned, through the work of Hertz and others, that when an electric current flows steadily in one direction in a cylindrical wire its intensity is the same in all parts of the wire; but if the current be of an oscillatory character, i. e., a current which rapidly reverses its direction, the condition no longer holds, and if the alternations are very rapid the interior of the wire may be almost free from current. If lightning then be a discharge of an oscillatory character, it may happen that the current down the lightning rod would be only *skin* deep. The experiments of Tesla and Elihu Thomson with currents of great frequency of alternation and very high potentials open the door to systematic study of discharges such as the ordinary lightning flash. In daily work currents of this type are coming more and more into prominence, and the time is not far distant when the lightning flash will be studied as an electrical discharge of this character. Protection entirely adequate for such discharges will then be forthcoming. Indeed, the reasons why present methods occasionally fail are now understood, and the proper remedies apparent.

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[1] Page VI. "Lightning Conductors and Lightning Guards."

And first let us see whether it is cheaper to insure than to provide proper protection. Foreign countries, especially Germany, France, and Great Britain, have recognized the importance of obtaining reliable data concerning the loss of life and damage to property through lightning. Perhaps the work of the Royal Prussian Bureau of Statistics[1] gives the fullest and most detailed accounts of the damage done by lightning in Germany, and the relative injury. Statistics are available for the number of houses struck, the number of fires, the character of the roofing, soil, etc.

In 1891 the Weather Bureau issued to its observers instructions to report at the end of every month the names, with corroborative dates and places, of all persons killed by violent windstorms, tornadoes, and lightning. During 1890 somewhat similar statistics had been gathered, but the returns were less systematically arranged. In preparing the Weather Bureau lists, observers were directed to examine all daily papers published in their respective cities, consult all local authorities, and make inquiry if necessary. Naturally, where dependence was had upon newspaper items, there resulted much duplication, but in verifying names and dates the duplicates quickly appear and exaggerated reports are easily confined to proper limits.

From the Weather Bureau records which have been tabulated, it appears that in the United States, for the five years 1890–'94, 1,120 lives were lost, an average of 224 lives per year.

It is also evident that these lives were practically all lost in five months—April to September—and that in June and July the maximum death rate occurs.

The Weather Bureau records unfortunately do not give information as to the extent of damage to property. To get at something like a fair commercial estimate of the destruction of property by lightning, I have made use of the "Chronicle Fire Tables" for the nine years 1885–'93. It is hardly necessary to remark that these tables are compiled from the reports of the fire departments, insurance companies, and the reports of fires in the public press, and represent a high degree of accuracy.

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[1] Beiträge zur Statistick de Blitzschläge in Deutschland; by Dr. Hellmann, Berlin, 1886.

From information contained in these volumes, the following tables have been compiled:

Fires caused by lightning.

Year.	Number of fires.	Loss.
1885 to 1890, inclusive	2,220	$8,386,826
1891	457	1,355,525
1892	839	2,921,484
1893	659	1,645,180

Or, in nine years, ending 1893, in the United States, and for the most part east of the Rocky Mountains, 4,175 fires, with a loss of $14,309,015.

It is very evident, therefore, that the damage done by lightning is no inconsiderable matter, to be lightly passed over or turned off by replies such as the one given by the Glasgow manufacturers. It is certainly worth while to erect the proper protective apparatus.

The following table shows the number of barns, stables, granaries, churches, and dwellings set on fire by lightning during the years 1890, 1891, 1892, and 1893:

Barns, churches, and dwellings fired.

Year.	Barns, stables, and granaries.	Churches.	Dwellings.
1890	363	29	121
1891	290	11	78
1892	495	29	177
1893	344	25	167

During ten years ending 1893, 2,679 barns, 129 churches, and 831 dwellings have been struck by lightning.

The question has often been raised whether there exists a periodicity in the number of lightning strokes. Statistics must cover a period of at least twenty years before an answer to this question can be given, but it is interesting to compare the number and kind of buildings struck for the last three years of which we have record.

Comparison of buildings set on fire.

	1891.	1892.	1893.
Barns, granaries, and stables	290	495	344
Churches	11	29	25
Country and general merchandise stores	5	6	8
Dwellings and tenements	78	177	167

Comparison of buildings set on fire—Continued.

	1891.	1892.	1893.
Electric light stations	1	2	1
Grain elevators	2	4	2
Grain fields	1	....	0
Grain, hay, and straw in stack	10	12	7
Ice houses	4	4	1
Lighthouses and life-saving stations (no other source of fire reported)	2	....	0
Livery stables	4	4	1
Lumber yards	2	1	0
Oil refineries	2	2	1
Oil tanks	2	22	7
Railroad depots	5	7	15
Telegraph and telephone offices	2	3	4

It is of particular interest to study the geographical distribution of the dwellings and barns *fired by lightning* in these three years. There are some notable increases in certain States, the reasons for which are not at present discernible. Attention is directed to the figures in bold-faced type, showing a marked increase as compared with the previous year.

Geographical distribution.

State.	Barns.			Dwellings.		
	1891.	1892.	1893.	1891.	1892.	1893.
Alabama	0	0	1	2	0	5
Arizona	0	0	....	0	0	....
Arkansas	0	0	1	1	0	0
California	0	0	1	0	0	0
Colorado	0	....	....	0	0	0
Connecticut	9	**23**	12	6	**16**	4
Delaware	4	5	1	....	....	0
District of Columbia	0	0	0	0	0	0
Florida	0	0	0	1	3	3
Georgia	0	0	4	2	2	3
Idaho	0	0	0	0	0	0
Illinois	17	7	**20**	7	**12**	10
Indiana	31	38	29	7	9	12
Indian Territory	0	0	0	0	0	0
Iowa	19	6	7	....	....	4
Kansas	1	2	2	....	....	1
Kentucky	3	4	4	....	....	1
Louisiana	0	0	0	3	4	0
Maine	21	23	13	7	**16**	3
Maryland	12	8	12	....	**6**	2
Massachusetts	12	15	13	8	**12**	11
Michigan	26	**70**	35	....	**13**	14
Minnesota	7	5	3	4	6	3
Mississippi	1	....	0	....	....	2
Missouri	2	1	11	2	3	**10**
Montana	0	0	0	0	0	0
Nebraska	1	....	10	....	....	2
Nevada	0	0	....	0	0	0
New Hampshire	2	2	7	....	....	1
New Jersey	14	**30**	10	3	7	7
New Mexico	0	0	....	0	0	0
New York	30	**117**	59	5	**23**	26
North Carolina	2	3	1	....	2	2
North Dakota	0	1	1	0	0	0
Ohio	26	26	18	6	4	13
Oregon	2	....	0	....	....	0
Pennsylvania	29	**73**	23	3	**23**	3
Rhode Island	1	4	3	....	2	**8**
South Carolina	3	....	0	....	....	....
South Dakota	3	3	0	2	2	0
Tennessee	0	0	2	0	1	1
Texas	4	7	4	....	....	5
Utah	0	2	0	0	0	0
Vermont	0	3	3	0	0	3
Virginia	4	....	6	....	2	1
Washington	1	0	0	1	0	0
West Virginia	1	2	1	0	1	0
Wisconsin	6	**11**	**27**	2	3	**8**
Wyoming	0	0	....	0	0	0

The statistics collected by the observers of the Weather Bureau show, in addition to the number of fires and estimated damage, the number of lives lost, the number of persons injured, and such other facts as seem of particular value in connection with lightning.

LOSS OF LIFE AND DESTRUCTION OF PROPERTY BY LIGHTNING IN THE UNITED STATES IN 1894.

In January no lives were lost so far as known.

In February 2 lives were lost, 2 persons injured, and 50,000 feet of lumber destroyed.

In March 6 lives were lost, 3 persons injured; and 2 barns, 2 churches, and 5 dwelling houses struck and damaged.

In April 14 lives were lost, 15 persons injured; 1 barn and 7 dwelling houses damaged.

In May 55 persons were killed by lightning and 34 severely injured; 12 houses were set on fire with a loss of not less than $35,000; 36 dwellings, 4 churches, 2 school houses struck, and more or less damaged; 58 horses and 22 cows not in stables were killed.

In June 96 persons were killed and 102 severely injured; 69 barns were damaged not less than $49,000; 49 houses, 30 cows, and 15 sheep not stabled were killed; 80 dwellings, 22 churches, 1 railroad depot, 1 oil tank, 1 grain elevator, 6 mills and factories were damaged; the loss in the eight last named being not less than $257,000.

In July 60 lives were lost, and 103 persons injured; 46 barns were damaged not less than $50,000; 45 dwellings, 12 churches, 2 academies, 3 mills or factories, and 2 railroad depots were struck; 24 horses and 13 cows, 5 mules, and 6 sheep, not stabled, were killed.

In August 78 lives were lost and 76 persons injured; 81 barns were burned with a loss of not less than $129,800; 41 dwellings were struck, 22 horses and 15 cows, not stabled, were killed; 5 churches, 2 academies (one with loss of $38,000), 2 mills, and 1 oil tank (loss $20,000) were struck.

In September 99 persons were killed and 14 severely injured; 56 barns were struck with loss of not less than $141,500; 42 dwellings, 2 churches were struck, 14 horses, not stabled, were killed.

In October 6 persons were killed and 2 severely injured; 2 barns valued at $3,000, 2 dwellings, 2 churches, and several stacks of grain were fired.

In November 1 dwelling was struck, valued at $3,000.

In December 1 barn in Ohio, 2 dwellings (one in San Francisco, Cal., where damage from lightning is almost unknown), were struck.

During the year 336 persons were killed and 351 severely injured; 268 barns barns struck with a damage of $407,500; 55 churches were struck, damage unknown; 261 dwellings and several oil tanks, factories and elevators, the damage amounting to not less than $351,000.

For purposes of comparison the following table has been prepared:

Loss of life in the United States by lightning.

	1890.	1891.	1892.	1893.	1894.
January	......	......	......	......	......
February	......	......	......	......	2
March	2	......	......	5	6
April	6	13	5	19	14
May	8	23	27	17	45
June	37	73	74	66	96
July	55	52	67	73	60
August	12?	34	54	18	78
September	......	9	15	8	29
October	......	......	6	2	6
November	......	......	1	......	......
December	......	......	2	1	......
Total	120?	204	251	209	336

According to the statistics of the German bureau, previously referred to, the frequency of lightning stroke varies somewhat with the character of the land. Thus, in their investigations it was found that in flat lands 400 to 540 buildings were struck out of 1,000,000, the rate varying in different localities.

The nature of the material used for roofing has also been considered. Classifying the various materials under the general heads "hard" and "soft," the German investigators found for ten years (1873–'83) for Schleswig-Holstein, that of all the buildings struck, 9 per cent of those having *hard* roofs and 68 per cent of those having *soft* roofs were set on fire. The nature of the building and the purpose for which it is used will, as we readily see also in our own statistics, influence the liability to stroke and fire.

The following facts[1] regarding the distribution of thunderstorms are of interest, though it is to be noted that the damage done may not be directly proportional to the number of storms:

> The region of the greatest number of thunderstorms is in the southeastern part of the United States. The line for 40 per year passes through southern Georgia, southern Alabama, and southeastern Mississippi. The number increases northeastward and the area in which less than 10 thunderstorms occur each year is confined to the coast of New England. * * * From May to June the maximum is in the northeastern and central States, especially in a region extending along the Mississippi Valley from Keokuk to Cairo. * * * For July the maximum extends from northern Montana to central Texas, thence to Georgia and thence northeastward to southern Maine; also in a small area about Lake Huron. The maximum for August occurs in the vicinity of Salt Lake, Utah, and along the Gulf and Atlantic coasts. It appears, therefore, that the maximum of thunderstorms comes earliest to the west and southwest of the Great Lakes, and gradually extends to the west, south, and east. A matter of especial interest is the occurrence of winter thunderstorms. The area of maximum frequency is in Louisiana and vicinity. * * * The general direction of approach in the United States is from the west. At Key West, Fla., the approach is from the east; at Galveston, Tex., from the northeast, north, or southwest.

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[1] Rainfall and Snow of the United States, p. 29, by Mark W. Harrington, Chief of U.S. Weather Bureau.

One interesting point which appears to be shown by statistical studies of lightning stroke is the decreased liability to accident in *thickly settled* communities.

It may be said, in general, that the risk in the country is five times greater than in the city. For ordinary dwelling houses, not unduly exposed in city blocks, lightning rods are hardly necessary, a very considerable protection being afforded by the tin roofing, numerous cornices, gutters, etc. The geological, as well as the topographical conditions, may have some influence upon the frequency of lightning stroke. According to the authority already quoted, if 1 represents the frequency of lightning stroke in a chalk formation, 2 will represent the liability for marl, 7 for clay, 9 for sand, and 22 for loam.

With regard to trees, the oak is most frequently, and the beech least frequently, struck. The values are something like, if 1 represents the frequency for the beech tree, 15 for pines, other trees generally averaged at 40, and 54 for oaks. Trees struck are most generally those standing in the clear or on the edge of forests, and in height averaging from 16 to 20 meters (52 to 66 feet). The trunk appears to be struck about three times as often as the boughs, and generally the stroke seems to travel to the ground. Only in three out of a hundred cases did it jump to other trees.

Mr. Symons,[1] in his paper on thunderstorms, instances 16 trees struck. About one-third of these were elms, with the oak, ash, poplar, in order following, and one case each of crab-lime and willow.

It is interesting to recall at this point, the record made by Hugh Maxwell as early as 1787, that the elm, chestnut, oak, and pine were often struck, the ash rarely, and the beech, birch, and maple never. This last, however, is not true. Indeed, it is not altogether plain just why some trees escape while others suffer. Capt. Maclear,[2] discussing the action of lightning during a thunderstorm on June 6 and 7, 1889, found a great number of trees struck within a radius of 4 miles, and set to work to discover if possible the cause of the selection of these particular trees. "For contrary to general expectations," he says, "they were not the highest nor the most prominent in their immediate vicinity." A cottage, a haystack, 2 poplars, a spruce, fir, and 5 oaks, in different places, were struck within this confined area.

The storm passed in a northwest direction with southeast wind, and it is apparent that the objects struck lie nearly in a line northwest and southeast, 3 miles in length. "The spruce was very prominent on the southern brow of the hill, with two arms nearly in line with the stem; one arm was thrown to the ground and the other blown down. At the juncture of the arms there was a great deal of turpentine which was thoroughly blackened." Hence, it is assumed that the prominence of the tree made it the best communication to earth, and that the collection of turpentine was raised to explosive temperature and split the tree, but a like good reason does not appear for the other objects struck. On the next day 6 oaks, a chestnut, and an ash, in various positions within one-half mile of a pond, and on the slope of ground near the pond, a young fir, and three young oaks; one-half mile south of Cranleigh 4 oaks; on Cranleigh Common an oak, and 1 mile northwest a chimney, a stable, and an oak (struck also on the day before) and a single oak occupying a fairly prominent position on the slope of high hills, 2¼ miles northeast.

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[1] Also, Appendix E. "Report of Lightning Rod Conference."

[2] "Quart. Journ. Met. Soc." 1890, p. 229.

This last tree was struck just before the rain commenced and was split; the other trees struck during the rain were only scored. "Hence," concludes Maclear, "it is not easy to see the cause of selection, for these trees were not the most prominent, nor were they on the highest ground in the vicinity, *the only feature the groups possessed in common being that they were all either near ditches which were full of running water, or else near temporary courses taken by the deluge of water from the higher to the lower ground.*[1] The most puzzling case is that of the young fir tree and 3 young oaks in the middle of the copse near the pond. They were not higher than the other trees on the copse, but there certainly was a temporary water course close to them; other trees, however, stood equally close to water. * * * Another curious case is that of the stable struck, which was overshadowed by tall elms, where it might have been supposed that these would have taken the stroke."

Some statistics of the damage done by lightning stroke in Belgium[2] in 1889 may be appropriately inserted here. Of 324 lightning flashes, 2 struck lightning rods; 123 struck buildings, setting 36 on fire; 16 struck persons; 96, trees; 81, telegraph and telephone lines; and others, miscellaneous. In other statistics we find that of 18 deaths due to lightning; 1 occurred within a dwelling, 11 out of doors, and 6 under trees. Contrasted with the cases of death resulting from lightning stroke, let us look at 43 cases of persons struck, with results not necessarily fatal, and we find that 20 of these were in doors, 23 out of doors, including 4 under trees. No records sufficiently extended and authentic are available to ascertain what proportion of persons struck by lightning are killed outright. I know of but one record, and in that of 212 persons struck 74 were killed. This question, which is of the greatest interest, is referred to again under the last of the rules given further on for the protection of life.

One of the peculiar and most common characteristics of the action of lightning is the *tearing off* or *throwing* effect. This, as we shall see further on, is just what might be expected from discharges of great frequency of alternation. Some interesting statistics are given by Parnell[1] on the mechanical tearing off and disruptive effects of lightning as distinguished even from the *heat* effects. He records 1,147 cases. Of these, 224 do not permit a determination of the character of the work done by the stroke of the remaining 923.

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[1] Italics mine.

[2] Evrard and Lambotte. *Ciel et Terre*, 1891; No. 7.

	Mechanical work.	Heat.
Persons and animals	52	79
Cloths, carpets, canvas, woolen, linen, and cotton goods	88	79
Masonry of all kinds	416	2
Glass, china, earthenware	82	5
Metal	206	173
Wood	254	98
Trees	63	4
Ground	60	....
Thatch, straw, etc	....	11
Gunpowder	....	15
Gas	....	19
Total	1,221	485

Col. Parnell gives, furthermore, the details in 278 cases to show the existence of an *upward* direction in the force of the stroke.

This, and the statement that "probably few persons are aware that lightning strokes are more apt to bend or break metal than to fuse it," are, in the light of the investigations of the past three years into the character of the lightning flash, easily comprehensible. A lightning flash being a break in the air (i. e., the dielectric) when the electrical strain exceeds a certain value, determined by several variables, the strongest mechanical effect may be found in any direction, upward or downward. Speaking popularly, flashes may go from cloud to earth, earth to cloud, or from cloud to cloud to earth.

II.—THE THEORY OF LIGHTNING CONDUCTORS.

Beyond doubt, Franklin proved his case that lightning rods were efficacious in the protection of buildings. An illustration of the action of lightning upon a rod is shown in Fig. 4. Buildings with conductors when struck by lightning suffered little damage compared with those without protectors.

The chief defects likely to occur are blunted points and breaks in the continuity of the connection. The function of a lightning rod is twofold; first, that of conducting the charge to earth, and second, the prevention of a disruptive discharge by silent neutralization of the cloud electrification. The latter explains why a rod terminates in a point and likewise why points in good connection with the ground are always *desirable* upon buildings. Indeed, points are somewhat like small water pipes connected with a large reservoir. If you have enough of them and a sufficient time you may drain the largest reservoir. Furthermore, when some sudden rise or flood occurs in the reservoir, these minute drains may be of service in keeping the height of the water down.

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[1] "Quart. Journ. Met. Soc.," Vol. VI, 1885. See also Col. Parnell's book.

In the case of lightning the points are the small escape pipes, the layer of air between cloud and earth the retaining wall, and the cloud electrification—or charge—the overflowing and destructive element. A large conductor, be it rod or tape, on the other hand is more like a large main or water way, which has its gate shut until the flood is imminent. Then the gate is suddenly opened and we try to compel the torrent to keep to the provided path. We trust in its ability to safely hold the flood. Generally it does. In perhaps nine cases out of ten, the lightning conductor, if it be such a one as we will describe later, does carry the flash to earth; but there are cases where the discharges have been heavy and overflows have resulted. To carry the lightning flash "the lightning conductor should offer a line of discharge more nearly perfect and more accessible than any other offered by the materials or contents of the edifice we wish to protect." To prevent the discharge "the conductor should be surrounded by points." These quotations are from the Report of the Lightning Rod Conference.

The statement that lightning always follows the path of least resistance, as commonly understood and stated, needs modification. True it is, that when the air is strained by being subjected to the electrifications of cloud and earth, the weakest spot gives away first, and this is apt to be in line with some small elevated knob or surface; but it is equally true, and is perhaps the more general case, that when a really vigorous disruptive discharge does occur, it is somewhat, as Dr. Lodge aptly puts it, like an "avalanche." As a matter of fact, we find from the study of actual cases where buildings have been struck, that lightning often disregards entirely metallic surfaces and points. What we should first know is, whether the condition is to be one of "steady strain"[1] or "impulsive rush"[1] discharge. In the case of "steady strain," the metal is apt to influence the path of discharge; in the case of an "impulsive rush" discharge, even *points* seem to lose their efficiency and become of little use.

In a letter[2] of an old British admiral there occurs a description of his being called upon to approve some specifications for a lightning conductor to be erected on a certain lighthouse. He was himself a believer in the "surface" theory of Harris; but thought that, to make sure, he would go and consult his friend Faraday. Faraday, who saw only the question of conductivity in the problem, said very positively that the solid rod was better than the tube (which gives greater surface with less copper), and that *solid volume was everything*, superficial area nothing. Moreover, if Harris says otherwise "then, he knows nothing whatever about it." The admiral straightway approved the solid rod conductor for the lighthouse. Within two or three days he met Harris, and bringing up the question was told by Harris "*surface* area is most important, and if Faraday says otherwise, then he knows nothing whatever about it!"

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[1] Terms used by Prof. Lodge.

[2] See report of Lightning Rod Conference.

Up to a certain point Faraday was right; a copper rod an inch thick is capable of carrying almost any flash of lightning, and is undoubtedly a great protector, but if, as we have reason to believe, the core is seldom given a chance to carry the current, why have it? The views of Sir W. Snow Harris, based as they were upon close study of many thousand cases of lightning action, are finding in the experiments of to-day the confirmation so long needed.

While not going into details regarding this question of the shape of the rod, let us emphasize the fact, so recently brought out, that if an electric current flows steadily in one direction in a cylindrical wire, its intensity is the same in all portions of the wire, as shown by Hertz, but that with a current of an oscillatory character, i.e., a current which rapidly reverses its direction, this condition no longer holds, and if the direction is altered very rapidly the interior of the wire, in our case the lightning rod, may be almost free from current.

In 1882 appeared the report of the Lightning Rod Conference; in many respects the most important contribution to the literature of the subject yet made. While so many foreign governments, and in particular France, had by means of officially constituted boards taken a governmental interest in the protection of the people from the dangers of lightning, the English-speaking people of the world aside from the few directions officially issued for the protection of magazines and lighthouses, remained without any authoritative utterance upon the subject; and while this conference itself did not have strictly official sanction, it carries, from the character of its make-up, a weight certainly as great, if not greater, than an official board. It was simply a joint committee of representative members of the Institute of British Architects, the Physical Society, the Society of Telegraph Engineers and Electricians, the Meteorological Society, and two co-opted members. As might be anticipated from such auspices, the report is an excellent one, and must stand for years as the embodiment of the most widely gathered information and well-considered decisions. The report is emphatically one based upon *experience.*

The famous free-for-all discussion which occurred at the British Association Meeting in 1888, so far as our judgment goes, simply proved that the decisions of the conference could not at present be disregarded. As the president of the meeting, Sir William Thomssaid, we have "very strong reason to feel that there is a very comfortable degree of security, if not of absolute safety, given to us by lightning conductors made according to the present and orthodox rules."

There are one or two further features to which attention may be called. There are some very prevalent misapprehensions with regard to lightning. For example: that it never strikes twice in the same place; that the most exposed place is always struck; that a few inches of glass or a few feet of air will serve as a competent insulator to bar the progress of a flash that has forced its way through a thousand feet of air, etc. These are alluded to in the following general directions.

III.—RULES FOR THE ERECTION AND MAINTENANCE OF RODS.

1. Erection of rods. Few questions have been so thoroughly discussed from practical as well as theoretical standpoints as that of the certainty of the protection afforded by properly constructed lightning rods. All barns and exposed buildings should have lightning rods. Ordinary dwelling houses in city blocks have not the need for rods that scattered houses in the country, and especially if on hill sides, have.

2. Use a good iron or copper conductor. If the latter, one weighing about 6 ounces to the foot, and preferably in the form of tape. If iron is used and it seems to be in every way as efficient as copper, have it in rod or tape form and weighing about 35 ounces to the foot. "A sheet of copper constitutes a conductive path for the discharge from a lightning stroke much less impeded by self-induction than the same quantity of copper in a more condensed form, whether tabular or solid." (Sir William Thomson.)

3. The nature of the locality (see Chapter I) will determine to a great degree the need of a rod. Places apart but a few miles will differ greatly in the relative frequency of flashes. In some localities the erection of a rod is imperative; in others, hardly necessary.

4. The very best ground you can get is, after all, for some flashes but a very poor one; therefore, do not imagine that you can overdo the matter in the making of a good ground. For a great many flashes an ordinary ground suffices, but the small resistance of $\frac{1}{10}$ ohm for an intense oscillatory flash may be dangerous. Bury the earth plates in damp earth or running water.

5. "If the conductor at any part of the course goes near water or gas mains, it is best to connect it to them. Wherever one metal ramification approaches another it is best to connect them metallically. The neighborhood of small bore fusible gas pipes and indoor gas pipes in general should be avoided." (Lodge.)

6. The top of the rod should be plated or in some way protected from corrosion and rust.

7. Independent grounds are preferable to water and gas mains.

8. Clusters of points or groups of two or three along the ridge rod are recommended.

9. Chain or linked conductors are of little use.

10. Area of protection. Very little faith is to be placed in the so-called area of protection. The committee that first gave authority to this belief considered that the area protected by any one rod was one with a radius equal to twice the height of the conductor from the ground. Many lightning rod manufacturers consider that the rod protects an area of radius equal to the height. The truth is that buildings are struck sometimes within this very area, and we now hold there is no such thing as a definite protected area.

11. Return shock. Some uncertainty exists on this point. The so-called "return stroke" is caused by the inductive action of the charged cloud on bodies within its influence, and yet some distance away from the place of the direct discharge. As explained by Lord Mahon, who first called attention thereto, the sudden return of the body charged inductively to a neutral condition, following the equalization at some distant place, is the cause of the return shock. We are beginning, however, to see more clearly into the character of the stress in the dielectric, preceding and during flashes, and it is only a question of time before the use of this term, "return shock," will be abandoned. Of far greater import are the terms "recoil kick" and "alternative path," as shown experimentally by Lodge to exist.

12. Upward motion of stroke. There is no reason to doubt that the discharge takes place sometimes from earth to cloud. That is to say, that while we now consider a lightning flash as something like the discharge of a condenser through its own dielectric, made up of excessively frequent alternations, say something like 300,000 times per second, the spark, or core of incandescent air, may seem to have had its beginning at the earth's surface. That is to say, the air gap breaks down first at a point near the earth.

13. Indifference of lightning to the path of least resistance. Nearly all treatises upon lightning up to within very recent times, assumed that lightning always followed the path of least resistance. "It is simply hopeless to pretend to be able," says Lodge, "to make the lightning conductor so much the easier path that all others are out of the question." The path will depend largely upon the character of the flash.

14. Any part of a building, if the flash be of a certain character, may be struck, whether there is a rod on the building or not. Fortunately, these are exceptional instances. The great majority of flashes in our latitudes are not so intense but that a good lightning rod, well

earthed, makes the most natural path for the flash. We have many instances, however (not to be confounded with cases of defective rods), where edifices, seemingly well protected, have been struck below the rods.

15. Parodox of parodoxes, a building may be seriously damaged by lightning *without having been struck at all.* Take the famous Hotel de Ville of Brussels. This building was so well protected that scientific men pronounced it the best protected building in the world against lightning. Yet it was damaged by fire caused by a small induced spark near escaping gas. During the thunderstorm, some one flash started "surgings" in a piece of metal not connected in any way with the protective train of metal. The building probably did not receive even a side flash. This is, therefore, a new source of danger from within, and but emphasizes the necessity of connecting metal with the rod system.

16. Lightning does sometimes strike twice in the same place. Whoever studies the effects of lightning's action, especially severe cases, is almost tempted to remark that there is often but little left for the lightning to strike again. No good reason is known why a place that has once been struck may not be struck again. There are many cases on record supporting the assertion.

17. As lightning often falls indiscriminately upon tree, rock, or building, it will make but little difference sometimes whether trees are higher than adjoining buildings.

18. It is not judicious to stand under trees during thunderstorms, in the doorway of barns, close to cattle, or near chimneys and fire places. On the other hand, there is not much sense in going to bed or trying to insulate one's self in feather beds. Small articles of steel, also, do not have the power to *attract* lightning, as it is popularly put, or determine the path of discharge.

19. Unnecessary alarm. Just in advance of thunderstorms, whether because of the varying electrical potential of the air, or of the changing conditions of temperature, humidity, and pressure, and failure of the nervous organization to respond quickly, or to whatever cause it may be due, it cannot be denied that there is much suffering from depression, etc., at these times. It is, perhaps, possible that these sufferings may be alleviated. Apart from this, many people suffer greatly from *alarm* during the prevalence of thunderstorms, somewhat unnecessarily, we think. Grant even that the lightning is going to strike close in your vicinity. There are many flashes that are of less intensity than we imagine, discharges that the human body could withstand without permanent serious effects. Voltaire's caustic witticism "that there are some great lords which it does not do to approach too closely, and lightning is one of these," needs a little revision in these days of high potential oscillatory currents. Indeed,

the other saying, "Heaven has more thunders to alarm than thunderbolts to punish," has just so much more point to it as it is nearer the truth. *One who lives to see the lightning flash* need not concern himself much about the possibility of personal injury from that flash.

20. Finally, if you should be in the vicinity of a person who has just been struck by lightning, no matter if the person struck appears to be dead, go to work at once and try to restore consciousness. There are many cases on record proving the wisdom of this course; and there is reason for believing that lightning often brings about suspended animation rather than somatic death. Try to stimulate the respiration and circulation. Do not cease in the effort to restore animation in less than one hour's time. For an excellent illustration of a case of severe lightning shock and recovery, due, it would seem, to prompt action by the medical gentlemen present, all who are interested may consult the "Medical News," August 11, 1888. A number of cases corroborative of this view are on record in various medical journals.

IV.—DIRECTIONS FOR PROCEDURE IN CASE OF APPARENT DEATH FROM LIGHTNING.

These directions are based upon Dr. Augustin H. Goelet's "How to Deal with Apparent Death from Electric Shock," reprinted by permission of "The Electrical World;" revised and modified for death from lightning, by Dr. W. F. R. Phillips, of the Weather Bureau. Dr. Goelet says:

> An electric shock may produce death in one of two ways, viz: (1) By producing destructive tissue changes, when death is absolute, or (2) by producing sudden arrest of the respiratory and heart muscles through excitement of the nerve centers, when death is only apparent; in other words, animation is merely suspended. The subject may be aroused from this syncope if efforts at resuscitation are not too long delayed.
>
> The alternating current, which is usually regarded as the most deadly, strange to say, nearly always produces death in this second manner.
>
> To say that a person has received a shock from a wire conveying a current of four or five thousand volts does not necessarily signify that the body has been subjected to the full force of the current, even if the meter does register nearly one ampere during the time of the accident. In view of the fact that the human body offers a resistance of several thousand ohms, which resistance is greatly increased by imperfect contact and by charring and burning the tissues at the points of application, it is not often that the internal structures or vital organs are submitted to a very considerable volume of current, though it apparently passes through the body. It must be borne in mind that when the clothing is moist with perspiration or wet with rain it offers a circuit of less resistance than the human body, and in this event the body receives only a shunt current very much less in quantity than the main current. The bulk of current in this instance passes over the surface and does not enter the body. This may explain the survival of some who have apparently withstood very powerful currents.
>
> *It must be presumed, therefore, that electricity seldom kills outright, though the condition of suspended animation, which it induces, would result in death if not counteracted.*

All things considered, it is rational to attempt the resuscitation of those apparently killed by electricity, and, if not too long delayed, the effort promises fair chances of success, provided proper means are instituted.

If the body has actually been submitted to a current of sufficient volume to produce destructive tissue changes, all efforts at resuscitation will of course be futile.

If, on the other hand, only respiration and the heart's action have been temporarily arrested, there is a condition of syncope simulating apparent death by drowning or from anæsthetics, and the physician knows that patients in this condition are frequently revived. Laymen will appreciate the nature of this condition if it is explained as one of exaggerated faint, and would not feel appalled upon encountering it if previously instructed how to cope with it. In an ordinary fainting spell the necessity to stimulate is universally appreciated. In syncope resulting from an electric shock stimulation is likewise indicated, but more vigorous measures are required. This is the only difference.

As said above, the direction to treat one shocked by electricity as one drowned may be misleading, as the conception of the layman of the necessities in this case would be to roll the body on a barrel. Let him understand that the condition is one of exaggerated faint; prompt stimulants are necessary. *The man must be made to breathe*, if this is possible, and the efforts to induce respiration must not be suspended until breathing is fully and normally restored, or until it is absolutely certain that life is extinct. This can not be assured in less than an hour's persistent, energetic, tireless effort.

DIRECTIONS FOR ARTIFICIAL RESPIRATION.

The body must be placed upon the back. A roll made of a coat or anything else convenient (*rolled* not folded) is placed under the shoulders, and must be sufficiently large to so prop the spine up as to drop the head backward. The operator should kneel behind the subject's head, grasp the elbows and draw them well over the head, so as to bring them almost together above it and hold them there for two or three seconds. Then he carries them down to the sides and front of the chest, firmly compressing it by throwing his weight upon them. After two or three seconds the arms are again carried above the head and the same maneuver is repeated at the rate of fifteen or sixteen times per minute. At the same time the tongue must be drawn out to free the throat. This manipulation stimulates respiration in the following manner, viz: When the arms are extended over the head, the chest walls are expanded, just as in inspiration, and if the throat is clear the air will rush into the lungs. When the arms are brought down to the sides of the chest, compressing it, the air is expelled, just as in expiration. * * * The operator must, however, appreciate the fact that this manipulation must be executed with *methodical deliberation* just as described and never hurriedly nor half-heartedly. To grasp the arms and move them rapidly up and down like a pump handle is both absurd and absolutely useless.

In addition to this, if an assistant be at hand, the tongue, held by a cloth or handkerchief to prevent slipping, should be seized and drawn forcibly out during the act of inspiration or when the arms are extended above the head, and when the chest is compressed it may be allowed to recede. The rythmical traction upon the tongue is in itself an excellent stimulant of respiration. It acts not only by freeing the throat of the tongue, which may fall back and obstruct breathing, but also by reflex irritation, through the frænum or bridle under the tongue being drawn forcibly against the lower teeth.

The procedure described and recommended by Dr. Goelet is that known as Sylvester's method. An equally efficacious method is that known as Howard's, which also keeps the passage through the windpipe free without the aid of an assistant, and is recommended for that reason. It is as follows:

Place the subject on his back, head down and bent backward, arms folded over the head (under no conditions raise the head from the ground or floor). Place a hard roll of clothing beneath the chest with the shoulders declining slightly over it. Open the mouth, pull the tongue forward, and with a cloth wipe out saliva or mucus. Thoroughly loosen the clothing from the neck to the waist (but do not leave the subject's body exposed, for it is essential to keep the body warm). Kneel astride the subject's hips, with your hands well opened upon his chest, thumbs pointing toward each other and resting on the lower end of the breastbone; little fingers upon the margin of the ribs and the other fingers dipping into the spaces between the ribs. Place your elbows firmly against your hips, and using your knees as a pivot press upward and inward toward the heart and lungs, throwing your weight slowly forward for two or three seconds, until your face almost touches that of your patient, ending with a sharp push which helps to jerk you back to your first position. At the same time relax the pressure of your hands so that the ribs springing back to their original position will cause the air to rush into the subject's lungs. Pause for two or three seconds and then repeat these motions at the rate of about ten a minute until your patient breathes naturally, or until satisfied that life is extinct. If there is no response to your efforts persistently and tirelessly maintained for a full hour, you may assume that life is gone.

No matter which method for respiration is used, it is important to maintain the warmth of the body by the application of hot flannels, bottles of hot water, hot bricks, warm clothing taken from bystanders, etc.

Firmly and energetically rub the limbs upward so as to force the blood to the heart and brain. If an assistant is present let him attend to this. Remember above all things that nothing must interrupt your efforts to restore breathing.

When swallowing is established, a teaspoonful of warm water, wine, diluted whisky or brandy, or warm coffee should be given. Sleep should be encouraged. In brief:

1. Make the subject breathe by artificially imitating the respiratory movements of the chest.
2. Keep the body warm.
3. Send for a physician.

Of the visible effects of lightning stroke upon the human body little more can be said than that sometimes burns, usually superficial, have been noticed, frequently red lines or markings, which are localized congestions of the small blood vessels of the skin. These from their irregularities and branchings have led to the fanciful idea of photographs of trees, etc.

V.—EFFICIENCY OF CONDUCTORS.

A practical application of the efficiency of lightning conductors will now be considered. On June 5, 1885, the Washington Monument, at Washington, D. C., at that time the highest edifice in the world, was struck by lightning. The barograph curve (Fig. 6) shows the fluctuation in pressure about the time of the occurrence of the stroke, 3.15 p. m. The storm itself was, as usual, a secondary depression in the southeastern or southern quadrant of a " low " area, and at Washington resulted in a high forenoon temperature, with a maximum of

90° F. about noon, with fresh southerly winds, veering to southwest at noon; to northwest at 1.28 p. m.; to northeast at 1.40 p. m., and backing to northwest at 1.42 p. m.; to east at 2.20 p. m.; to northwest at 2.37 p. m., and veering to northeast at 2.40 p. m., whence it shifted to southwest at 3.02 p. m.; to northwest at 3.10 p. m., and at 7 p. m. was blowing steadily from the north. The first thunder was heard at 1.07 p. m., and rain began at 1.23, ceasing at 2 p. m., commencing again at 2.20 p. m., and ending at 3.05 p. m. Thunder continued at frequent intervals to 3.50 p. m. The rain was at times heavy, and hail fell in the northern part of the city. Amount of rainfall at Signal Office, 0.61 inch.

Colonel Casey, U. S. Army, the engineer in charge of the construction of the monument, requested Profs. Rowland, Newcomb, and Mendenhall to examine the part struck and suggest what precautions should be taken to ensure the safety of the monument. It is proper to remark that the monument had been for all practical purposes finished and had already experienced storms of seemingly greater violence.

From the letter[1] of the commissioners charged with the completion of the monument, we find that "a considerable amount of unexpected work" was performed in the erection of rods and points to protect the obelisk from lightning. "The lightning protectors as established for the monument were commenced in January, 1880, and were finished in January, 1885," practically the date of completion of the monument. The elevation of the solid aluminium pyramid (which weighs 100 ounces and is 8.9 inches high and 5.6 inches square at base, with angle at the vertex of 34° 48′) is 555 feet (169.16 meters).

The conductors consist of the four hollow wrought-iron Phœnix columns, supporting the elevator machinery. The bottoms of these four columns rest upon and are bolted to cast-iron shoes, standing upon the floor of the large drum pit, * * * and the shoes are connected to ¾-inch soft copper rods, led to the bottom of a well in the center of the foundation. This well is 32 feet 10 inches in depth below the bottom of the drum pit and 15 feet 8 inches below the bottom of the masonry foundation, and the water stands in it permanently 2 feet 8 inches above its bottom. After the copper rods were inserted the well was filled up with clean sharp sand for a depth of 15 feet 8 inches, or up to the level of the bottom of the old rubblestone foundation of the monument. These four columns so arranged at their bases, *and always projecting above the top of the shaft, were continually lengthened as the building of the shaft progressed, and for the five summers during which the masonry was in progress acted as the lightning conductors of the edifice.*[2] No disruptive discharge of electricity was experienced during those years." When the marble pyramidion was completed, December, 1884, these four columns were within this marble covering, and from the extremity of each column a copper rod ¾ inch in diameter was run to the top stone and there united in a copper rod 1½ inches in thickness, which passed vertically through the cap stone and was screwed into the solid aluminium pyramid.

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[1] Senate Ex. Doc. No. 6, 49th Congress, 1st session.

[2] Italics mine.

The conductors "when tested, gave an electrical resistance of 0.1 ohm from the tip of the terminal to the copper rods at the base, and 2.2 ohms for the ground connections, making a total resistance of 2.3 ohms for the conductor. The system was entirely completed and connected on January 20, 1885."

On April 5, 1885, during the passage of a heavy thundercloud over the monument, at least five immense sparks or bolts of electrical light were seen within a period of twenty minutes to flash between the terminals and the cloud without audible sound to the observers. A careful examination of the conductors and shaft after this phenomenon failed to reveal any effects from these discharges.

On June 5, however, during the thunderstorm described above, a disruptive discharge was seen to pass between the summit of the pyramidion and the cloud. Upon examining the structure a crack was discovered in the stone on the north face of the pyramidion just under the top stone, extending through the block in a line nearly parallel to the northeast corner and about 8½ inches from it. (Fig. 5.) The fragment was pressed outward about ¾ inch at its bottom, chipping a small piece off the lower corner of the top stone into which it was locked, and was easily forced back to place and bolted to the solid stone from which it had been torn.

The recommendations of the gentlemen above named, who were asked to make a careful examination, were, in short, that the interior conductors should be connected "with a system of rods and a greater number of points, to be located upon the exterior of the pyramidion." Four ½-inch copper rods were fastened by a band to the aluminium terminal and led down the corners to the base of the pyramidion, and then through the masonry to the columns.

"As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods ½ and ¾ inch in diameter, respectively, furnishing 16 rods in all, connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the 11 highest horizontal joints of the masonry of the pyramidion they are connected to each other all around by the other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are gold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these points in all."

Eight years have now passed since the alterations were made and the monument stands uninjured. Unquestionably, standing as it does, 555 feet high, in the center of flat, well-watered ground, it constitutes a most dangerous *exposure* for lightning flashes. No better illustration of the value of lightning conductors can be asked.

VI.—PROTECTION OF BARNS BEFORE AND AFTER HARVEST.

The question is sometimes asked " Are thunderstorms more destructive to barns after harvest than before ?" The following reasons have been advanced as favoring an affirmative answer.

1. Before harvest the stalks of the growing grains and grasses, with their many points and heads, act as conductors of electricity, and serve as discharging points, to some degree neutralizing the electric stress in the air. After harvest the fields are more or less bare and the electric tension must be relieved through buildings and prominent features in the landscape.

2. The barn filled with crops is warmer than one that is empty, and is also more inflammable; if struck by lightning, it is more likely to be destroyed by fire. Packed hay, for example, naturally makes a barn or stable warmer than its surroundings, and with the warmth there is more or less moisture. Uprising warm currents of air probably form which, while not strong ordinarily, may be accentuated during thunderstorms, and play a significant part in determining the line of discharge. And, finally, barns, as a rule, are located on hills or hillsides, in positions to experience the maximum effects of currents due to heating or topography.

Before using the statistics given below it should be said that the farmer and the whole community notice the destruction of a barn filled with the produce of a year, more than they would notice the loss of an empty barn. Hence, some cases of empty barns have probably been passed over as hardly deserving notice, while all the cases of stocked barns have probably been reported.

The Weather Bureau statistics for 1894 show that, previous to August 1, 130 barns were struck, with a loss of $134,000. After August 1, 138 barns were struck, with a loss of $273,500.

Comparing these with persons killed, churches and dwellings struck, we have—

Before August 1, 223 persons killed, 173 dwelling, 40 churches.

After August 1, 113 persons killed, 87 dwellings, 15 churches.

It therefore appears that a barn is more liable to be struck when filled with crops than when empty.

o

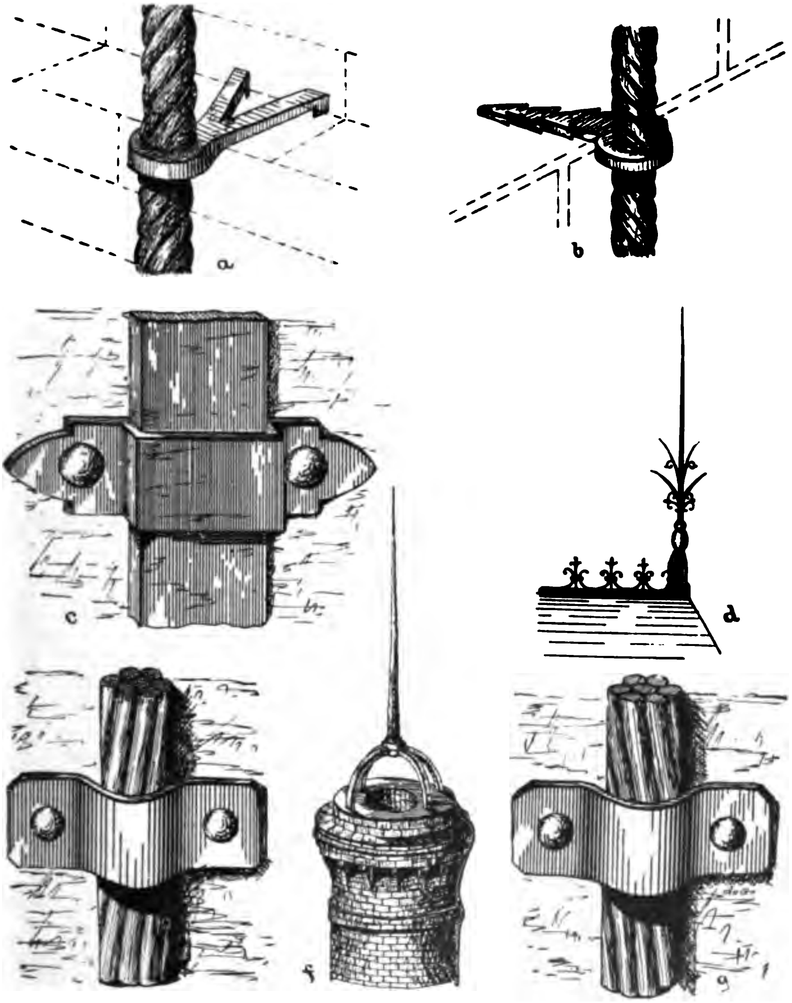


Fig. 1. Conductors and fastenings. From Anderson, and Lightning Rod Conference Report.

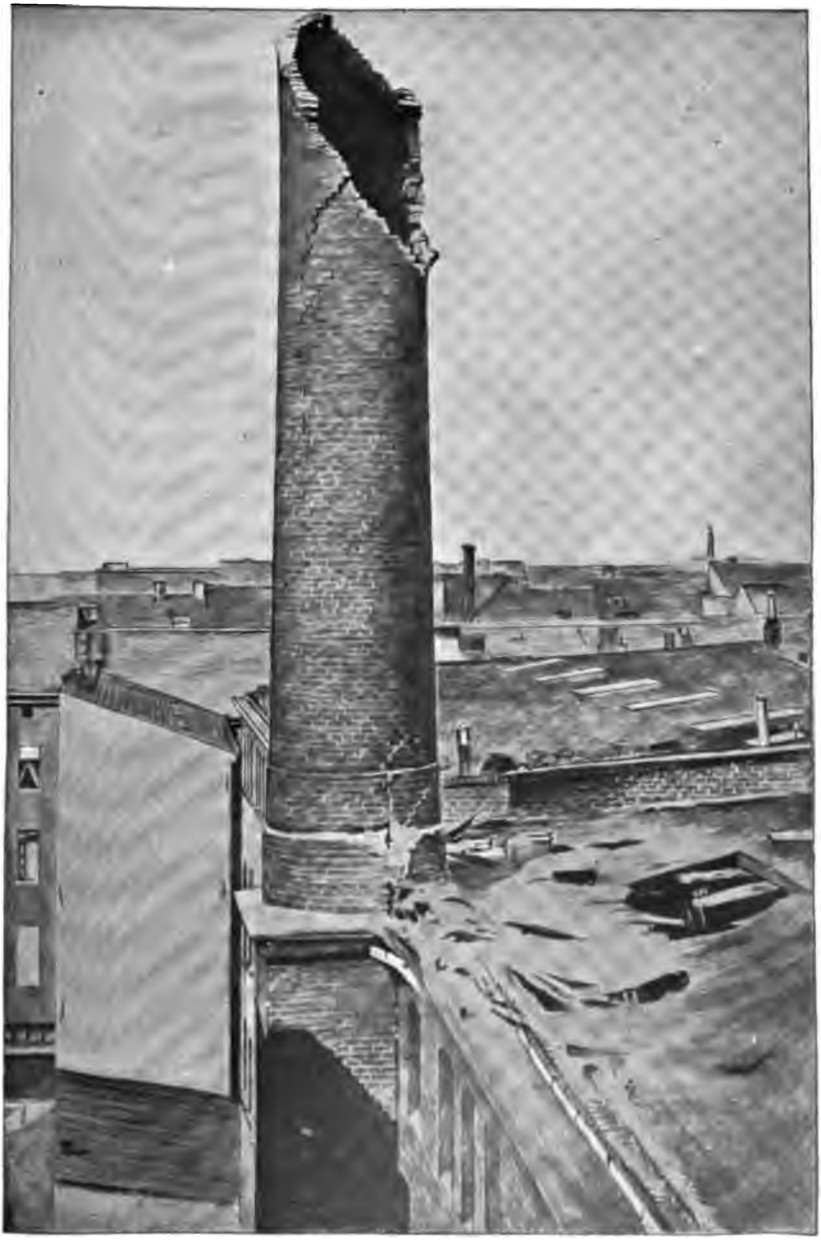


Fig. 2. Chimney, struck July 29, 1890. From *Elec. Zeits.*, Grebel.

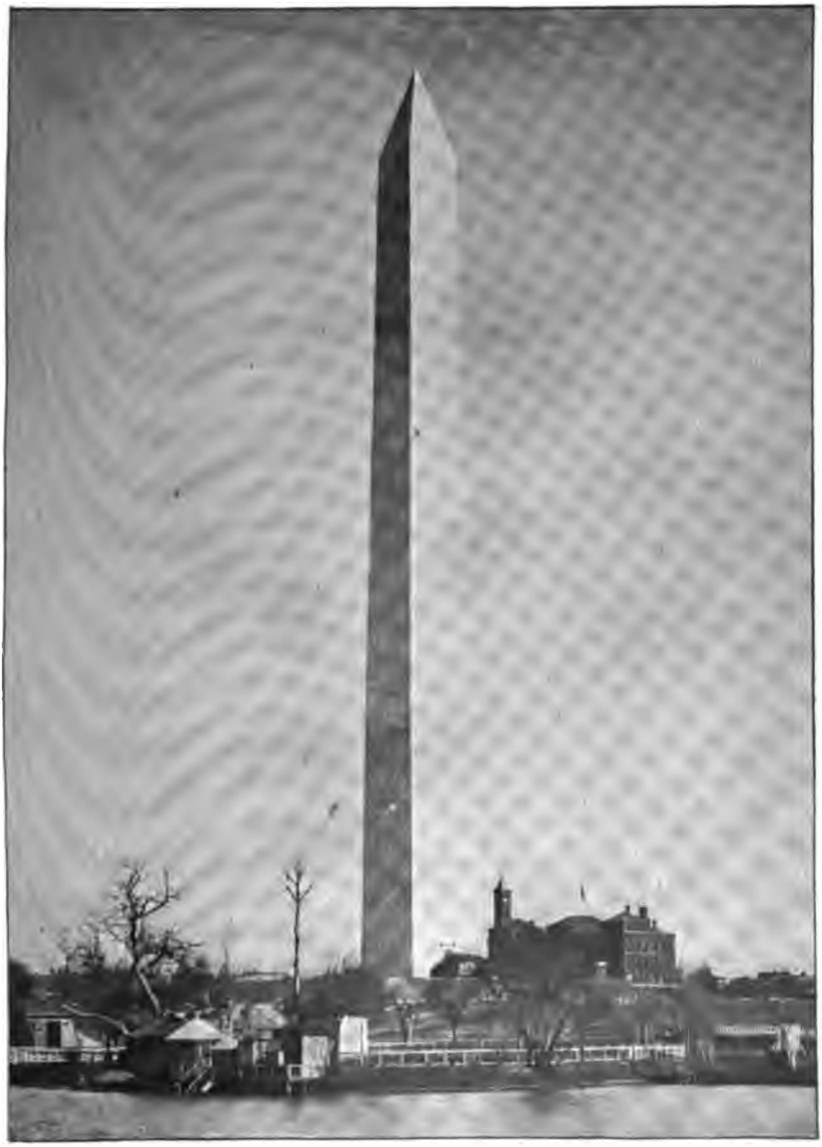


Fig. 3. Washington Monument, struck June 5, 1885.

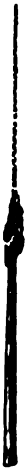
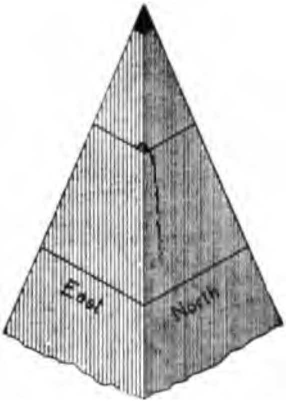


Fig. 4. Rod melted by lightning. From Franklin's Works.



◆ Aluminium tip weighing 100 oz.
Nearly 9" high 5½" square at base.
Height from ground 555 ft. (169 metres)

Struck April 5th 1885 without damage
" June 5th " crack on North
face just under top stone, extend
ing through the block in a line
nearly parallel to NE corner.

Fig. 5. Aluminium tip of Washington Monument.

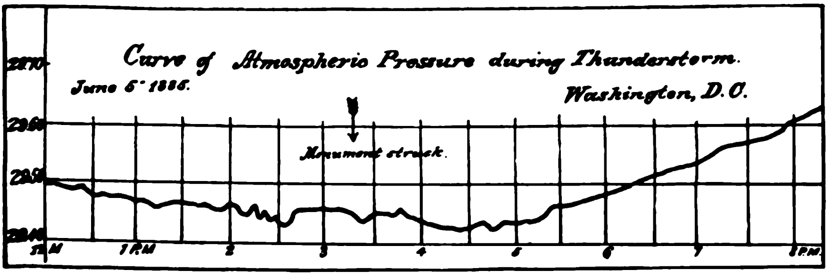
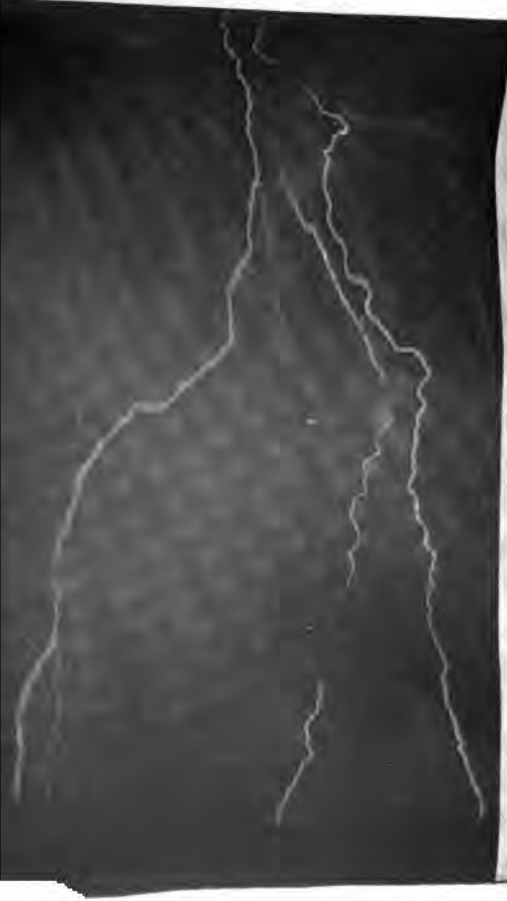


Fig. 6. Curve of barometric pressure.



le flash. From "Pop. Sci. Monthly," 1893, McAdie.

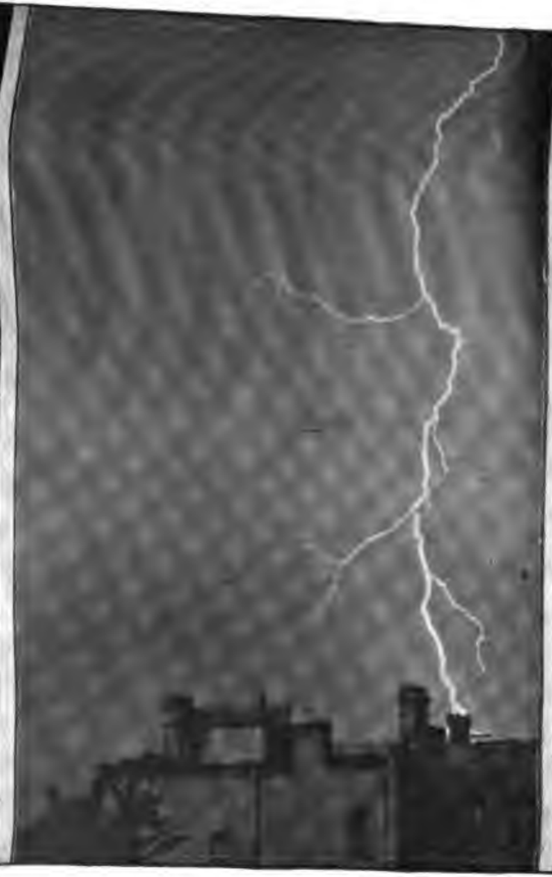


Fig. 8. Destructive flash. From photograph by McAdie.

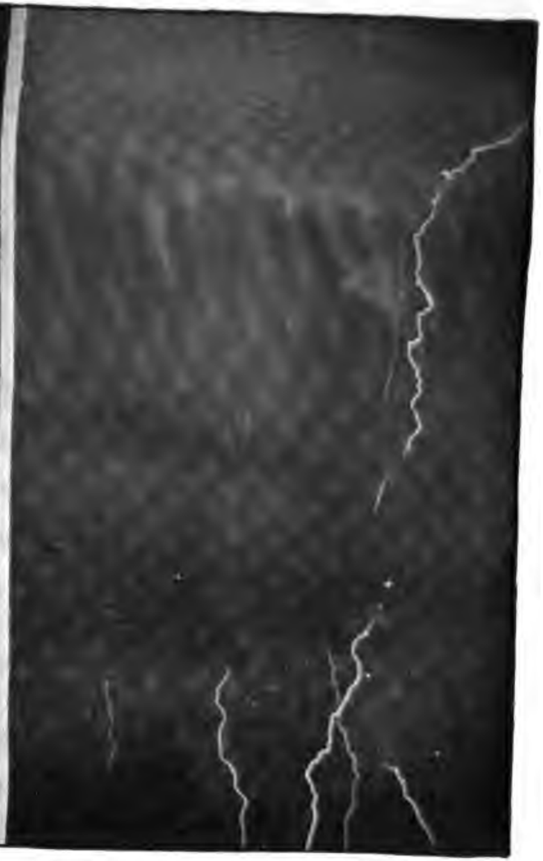


Fig. 9. Cloud and multiple flash. From photograph by McAdie.

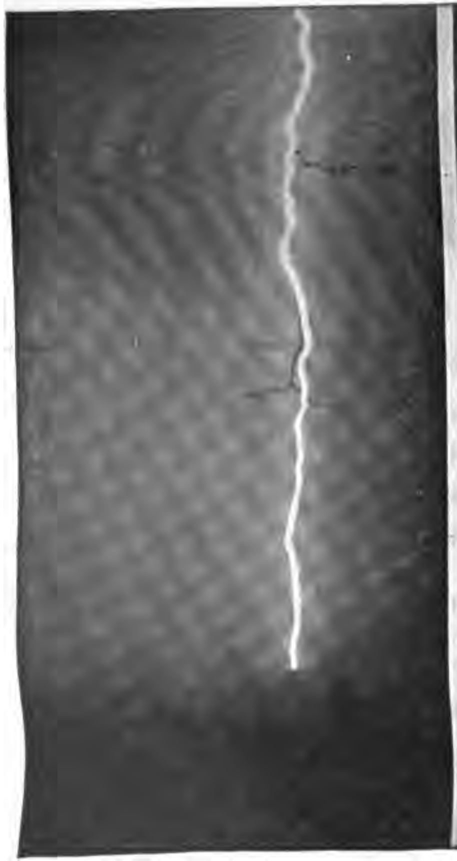


Fig. 10. Impulsive rush and so-called dark flashes. From "Pop. Sci. Monthly," McAdie.

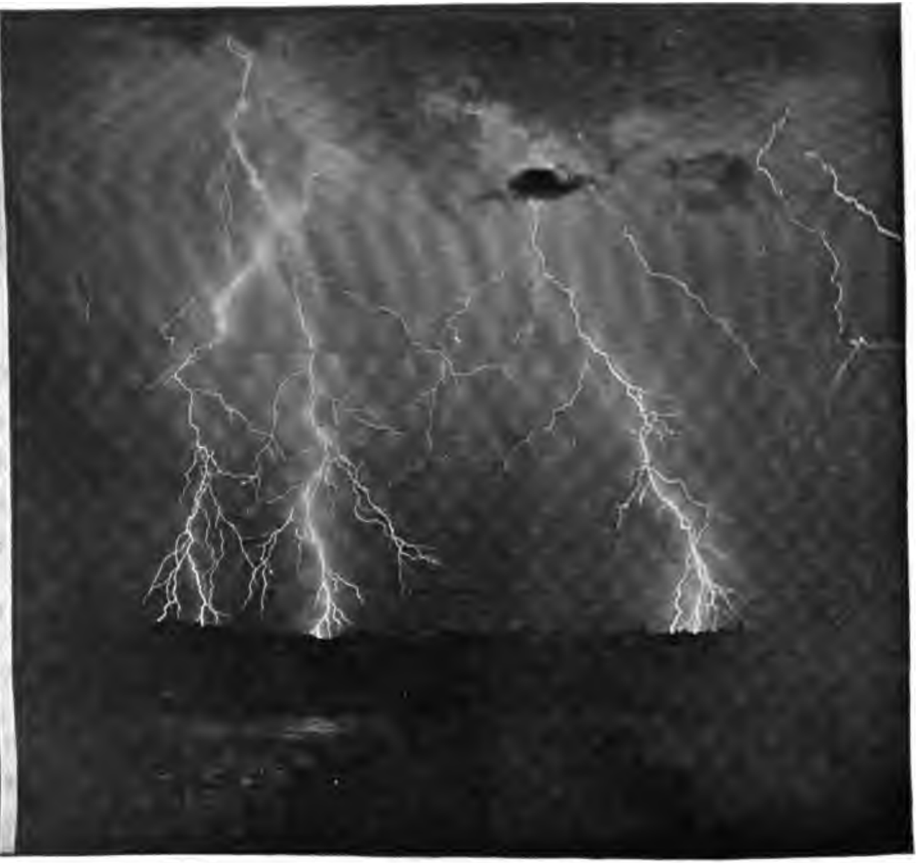


Fig. 11. Multiple flash. From "Scribner's Mag.," A. Binden.

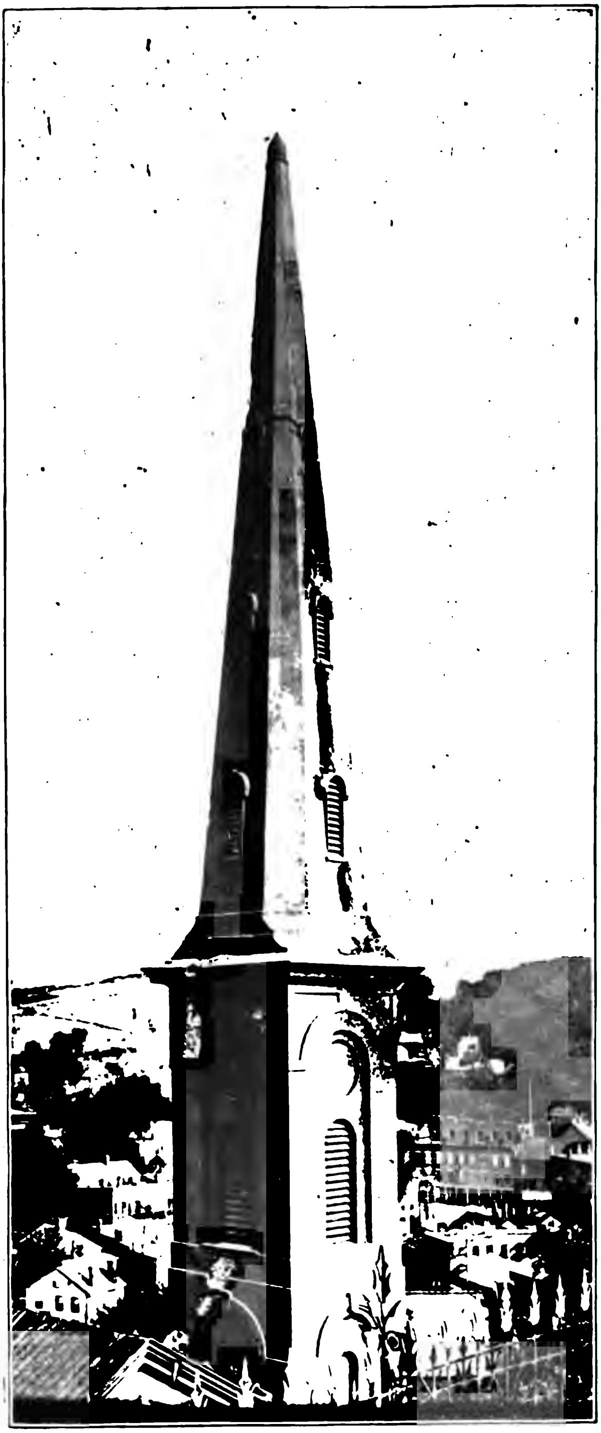


Fig. 12. Spire (198 feet, brick and brownstone) struck July 29, 1894. From "Scientific American," F. J. Moulton.

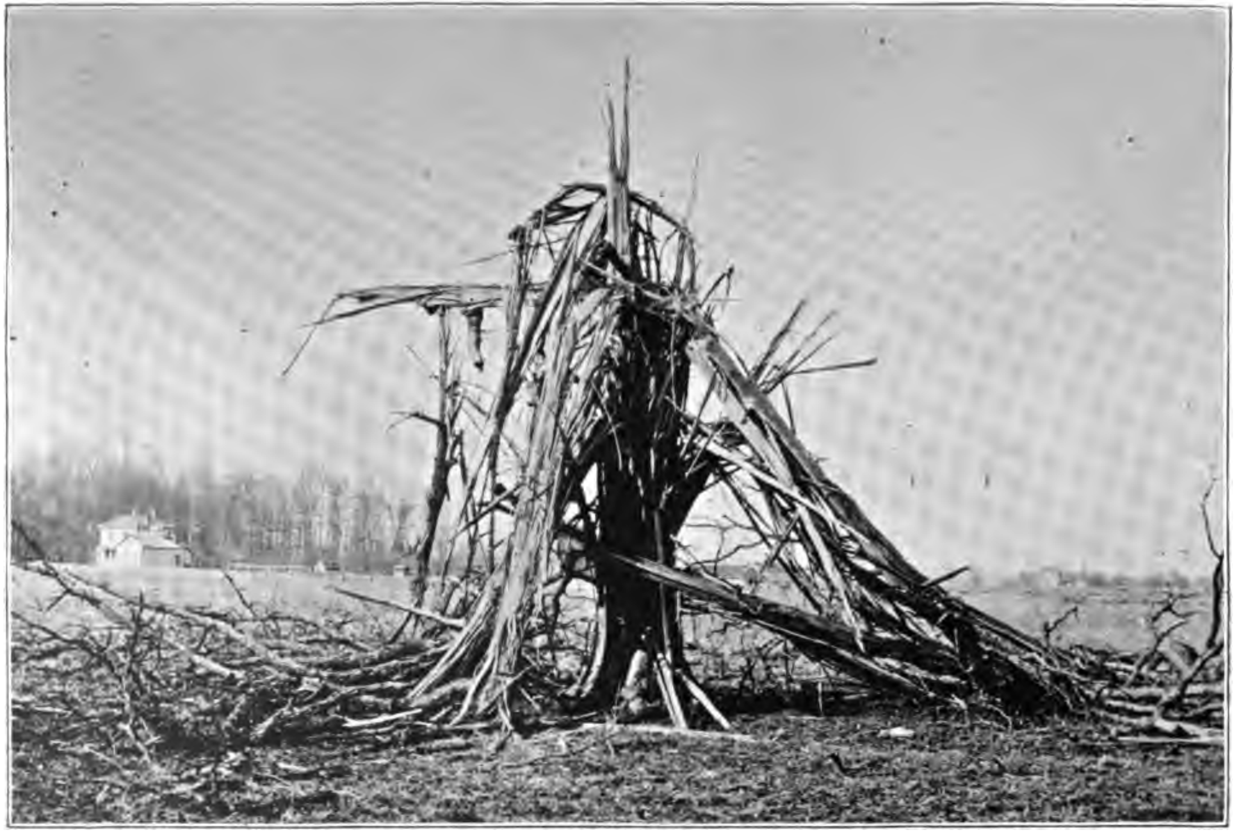


Fig. 13. Burr oak shattered by lightning March 15, 1894. From "Scientific American," Frank Woodmancy.

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WEATHER BUREAU.

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BY

L. E. JEWELL,

UNDER THE GENERAL SUPERVISION OF

PROF. H. A. ROWLAND,

OF JOHNS HOPKINS UNIVERSITY.

WASHINGTON:
WEATHER BUREAU.
1896.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., September 21, 1895.

Sir: I have the honor to transmit herewith a paper entitled "The Determination of the Relative Quantities of Aqueous Vapor in the Atmosphere by means of the Absorption Lines of the Spectrum." This has been prepared by Mr. L. E. Jewell, under the general supervision of Prof. Henry A. Rowland, of Johns Hopkins University, Baltimore, Md., and its publication as Weather Bureau Bulletin No. 16 is recommended.

Very respectfully,

Willis L. Moore,
Chief.

Hon. J. Sterling Morton,
Secretary.

THE DETERMINATION OF THE RELATIVE QUANTITIES OF AQUEOUS VAPOR IN THE ATMOSPHERE BY MEANS OF THE ABSORPTION LINES OF THE SPECTRUM.

By L. E. JEWELL.

The investigation upon which the present report is based was begun by me, in accordance with the recommendation of Prof. Henry A. Rowland, January 16, 1892.

In my preliminary report of June, 1892, I expressed the belief that much more satisfactory results would be obtained if the investigation of the "rain band," which had then been carried on for about six months, were continued so as to include results for a whole year.

This has been done, and I now have observations from January 16, 1892, to July 31, 1893, inclusive. Those for the latter part of July and during the months of August and September, 1892, were made by Dr. C. P. Cronk and G. N. Wilson of the Baltimore station, U. S. Weather Bureau, to whom I am much indebted.

This report includes the results obtained for the period from January 16, 1892, to January 31, 1893; the observations from the latter date to July 31, 1893, not being as yet reduced.

Observations were made both by eye and by photographic means, but the latter method was soon discontinued as unsuitable for the purpose and dependence placed upon eye observations alone.

A photographic map of that portion of the solar spectrum from wave lengths 5880 to 5950 was used for selecting a suitable series of solar and water-vapor lines for purposes of comparison (see Fig. 1). The study was confined to this region because there were no entirely suitable photographs at hand of the rest of the rain band, though there are a number of lines in the rest of the band that would be of value in intensity comparisons, as also would be the series of water-vapor lines in the neighborhood of the hydrogen line "C."

The method of observation used was to estimate the intensity of a water-vapor line in terms of the solar line most nearly equal to it in intensity, and in close enough proximity to render the comparison easy and sufficiently exact. One observation generally included several comparisons.

A more exact method would have been to make the observation when such a pair of lines (one solar and one water vapor) were of equal intensity, as the eye is very reliable for such comparisons, but much less so in estimating differences of intensity. This, however, was impracticable under the circumstances, both because of the greater length of time it would require for observations, and because it would make necessary a more extensive series of comparison lines than had been selected in the region of the spectrum to which I had limited the work.

Having selected a series of comparison lines, it became necessary to determine the relative intensities of both the solar and the water-vapor lines used in the comparisons, in order that the observations might be available for actual measurements of intensity and might mean something really definite instead of mere guesswork. For this purpose a photographic scale was constructed, consisting of a series of lines regularly increasing in intensity from a line barely visible to others as strong as were desired.

A large, narrow slit was used, with a gaslight behind it and a plate of ground glass between them, to produce a more even light. A series of images of the slit were then made upon a photographic plate held in a camera, the lens of which had been covered with a piece of wire gauze, fine enough to produce a shading to the edge of the lines and a somewhat diffuse appearance of the lines themselves, but not sufficiently fine to produce any definite side lines due to diffraction fringes.

In the scale thus constructed the exposures were so timed as to be in geometrical ratio, the object being to form a scale of lines whose intensity should vary, as the geometrical series 1, 2, 4, 8, 16, etc. These lines formed the principal divisions, while, to facilitate measurements, an intermediate line was added by making the ratio of the series 1.414 or $\sqrt{2}$.

A fine-grained plate was used and so developed as to secure the best gradation and the clearest background obtainable. In this way a scale was produced, the lines of which closely resembled those in the spectrum of the earth's atmosphere and the better class of lines in the solar spectrum. The scale answered very well for preliminary work, but has several defects, which would be objectionable in more refined work. It is, however, possible to produce a photographic scale which will be entirely satisfactory. It is not true that a series of lines thus produced vary in intensity exactly as a geometrical series, but this is approximately true, and consequently such a scale possesses some of the advantages of a table of logarithms. By its use variations in the spectrum as a whole, such as are caused by the use of different gratings and different orders of spectra, with more or less diffuse light and different widths of slit, can be expressed by a constant, by the application of which observations made with different gratings under different circumstances can be reduced to standard conditions. This was shown experimentally, during the progress of this investigation, by the fact that measurements made in both the first and second order spectra of the grating used differed by a constant, and measurements of the different lines of the oxygen bands differed by constants, irrespective of the elevation of the sun and the order of spectra or width of slit used. As a consequence of the properties of such a scale all necessary computations and reductions can be greatly simplified and shortened. The observations included in the scope of this paper have only been partly thus reduced, though had the method been extended much labor and time might have been saved.

In measuring the intensities of the solar lines the scale was held in one hand and an eyepiece in the other, and the lines of the scale brought into focus with the solar line to be measured, the latter being brought into position between the two lines of the scale most nearly of the same intensity as the line to be measured. Holding the scale in the hand is not an ideal way of measuring and is not to be recommended, but it answered the purpose of a preliminary set of measurements, and there was no other convenient arrangement available. The relative intensities of the water-vapor lines should have been measured in this way, making several determinations with different degrees of humidity of the air, but this was not done, partly because of the lack of time required for making such measurements and partly because, under the conditions prevailing in Baltimore when the measurements were made, the conditions, otherwise favorable, occurred when the sun was nearing the horizon and the intensities of the lines were changing too rapidly. Under these circumstances a much less desirable plan was adopted, viz, that of selecting those observations which included a comparison of both the lines to be measured and of the line taken as a standard (l_2) with solar lines, plotting the values thus obtained and deriving in this manner the relative values of the various water-vapor lines selected in terms of the one taken as standard. This plan is not to be recommended, but was the only one that seemed to be available.

In the same way the relation of eye estimates of differences in intensity to scale values was determined by thus selecting observations which were considered most suitable for the purpose. The results were plotted and a curve drawn representing the relation of eye estimates to scale values, and by which the differences in intensity as estimated by the eye were reduced to scale values, when the lines compared were not of equal intensity. This determination was not altogether satisfactory, but answered fairly well, as lines were generally selected for comparison which differed but little in intensity.

In Table II are given the intensities of the solar lines used in terms of the standard line selected (Q) with their approximate wave lengths.

In Table III are given the water-vapor lines used, with their intensities in terms of the line selected as standard (1_1) and their approximate wave lengths.

These values are not so accurate as might be desired, and are known to contain some errors, but on the whole they are fairly well determined, and I do not think it would be worth while to make a redetermination by the same method.

Considerable trouble was occasioned by a few of the lines being partly solar and partly water vapor, necessitating special observations to determine how much of the total intensity was due to each source.

Unfortunately, one of the most useful lines, and the one most used for low sun observations, was found to be of this character. It is a double solar line at wave length 5914.384, and has a water-vapor component coincident with the red component of the double.

Having finished the determination of the relative intensities of the lines selected and completed a series of observations, the results were put in tabular form and the reductions made as follows: The table (I) begins with the date of the observation in the first column; then follows what may be called the astronomical data, viz, the time (T) according to "eastern standard" time; the hour angle (t), plus values representing values west of the meridian and minus values those to the east; the amplitude (A), reckoned from the south point, the signs being the same as for the hour angles; the apparent zenith distance (z), the correction for refraction having been made.

Then follows the amount (a) of atmosphere passed through by the sunlight at the given angle, and in the next column is given the factor (β) for reducing the intensities of the water-vapor lines as observed to what they would be were the sun in the zenith. This factor is only approximate and varies according to the season, but only the mean value for each month is used.

Then follow the original observations upon the various water-vapor lines, given in terms of the solar line with which they were compared.

The next series of columns give these values so reduced as to represent the intensity of the lines observed in terms of the standard solar line (Q).

In the next series of columns are the respective resulting values of the intensity of the standard water-vapor line (1_1) in terms of the standard solar line (Q).

Next is the column of means and then the reduced means, giving the means multiplied by the reduction factor (β). This represents the value of the means reduced to what they would be were the sun in the zenith.

Then follow the meteorological data, viz, the absolute humidity (h)

Date.	Tim T	tandard water-vapor ine (l.).			Resulting intensities (l.).		Meteorologic conditions.					
		g	h₁	o₁	Mean. m.	Reduced mean. β m.	Absolute humidity.	Dew-point.	Relative humidity.	Temperature.	Pressure.	Rainfall.
							G.p.c.f.	°F.	%	°F.	Inches.	Inches.
1892. Jan. 16	8.00	....	....	....	....	....	0.957	18	76	19.0	30.550	0.00
	4.00	0.620	....	....	0.620	0.156	....	....	....	....	....	....
	4.10	....	....	0.695	0 693	0.158	....	....	....	....	....	....
	4.30	....	0.950	....	1.000	0.173	....	....	....	....	....	....
	4 50	....	....	1.760	1.760	0.215	....	....	....	....	....	....
	8.00	....	....	....	....	....	1.298	20	87	23.0	30.396	0.00
		l₂	o₁	p₁								
1892. June 20	8.00	....	....	....	....	....	7.493	68	73	78.3	29.859	0.33
	12 35	0 859	0.730	....	0.850	0.786	....	....	....	....	....	....
	3.40	1.042	0.910	0.980	1.000	0 519	....	....	....	....	....	....
	5.15	1.930	0.900	....	1.600	0 491	....	....	....	....	....	....
	8.00	....	....	....	....	....	8.521	72	79	79.0	29.799	Trace.
		o₁	p₁									
1893. Jan. 31	8.00	....	....	....	....	....	1.745	27	70	35.6	30.245	Trace.
	9.45	....	0.575	....	0.574	0.251	....	....	....	....	....	....
	12.30	....	....	....	0.370	0.209	....	....	....	....	....	....
	3 00	....	0.550	....	0.525	0.226	....	....	....	....	....	....
	4.57	1 830	....	....	1.850	0.266	....	....	....	....	....	....
	8.00	....	....	....	....	....	1.892	29	75	35.0	30.325	0.00

hat for purely atmospheric lines.

or the amount of water vapor contained in the air at the Baltimore station, given in grains per cubic foot; the dew point (*D. P.*); the relative humidity (*R.H.*); the temperature of the air (t); the height of the barometer (b), corrected and reduced to sea level; the precipitation (p) for the preceding twelve hours.

For comparison with meteorological data, the midday observation is much the most valuable, as the reduction to standard conditions (the conditions that would prevail were the sun in the zenith) is less liable to error. Consequently pains were taken to secure as complete a set of midday observations as possible. In addition to these a set of observations at various altitudes of the sun from noon to sunset were made every few days, in order that satisfactory curves for reducing observations to standard conditions might be constructed.

Considerable attention was also given to observations made upon the approach of both general and local storms and during the approach and prevalence of "cold waves." Observations were not confined to the water-vapor lines, but were occasionally made upon the various lines of oxygen, as it was desired to find the curve representing similar series of observations for one of the least changeable gases of the atmosphere. For this purpose oxygen lines were observed in the same manner as were the water-vapor lines, and, in addition, they were measured frequently by the scale, and the two methods were found to give the same results.

The observations were reduced and plotted and curves drawn representing approximately the mean monthly results. These monthly curves were used to reduce the observations to standard conditions. The daily curves differed considerably during the month, especially during spring and fall, but it was considered best for this investigation to only use a monthly mean curve.

In Table IV the intensity of the standard water-vapor line at various altitudes of the sun, during the different months of the year, is given as taken from the mean monthly curves referred to. In addition are given the intensities representing specially interesting conditions, viz, the readings from the curve of January 10, 1893, representing the curve for a "cold wave," and also the mean of the curves for July 14, 15, 16, 17, and 18, 1893, during the prevalence of warm, humid, weather conditions. In the same table are also given the results for oxygen. As this varies scarcely any during the year, a single curve suffices to represent it. The intensities given under oxygen are those of the first line in the tail of a (i. e., the oxygen line a), in terms of the same standard solar line (Q) used for comparison with the water-vapor line.

A study of the values of the intensity curves, as given in Table IV, brings out some interesting results. Not only are the intensities for the summer months much greater than for the winter months, but the forms of the curves, or their slopes, are quite different and also decidedly different from the form of the curve representing oxygen, showing that the character of the distribution of water vapor in our atmosphere is greatly different from that of oxygen and also greatly different at different seasons.

An interesting fact is the similarity in the curves for December, January, February, and March; the rapid change in the curves during April and the beginning of May; the gradual changes after August and during the fall months. The most remarkable difference, however, is between the conditions prevailing during cold waves and very warm, humid weather. The distribution of water-vapor during cold waves seems to be much like that of oxygen, while during warm, humid weather it is almost entirely different.

In Table IV the values given in parentheses are somewhat uncertain, observations not having been made at these altitudes; the horizon as seen from the heliostat of the spectroscope is clear only during part of the spring and winter, and the highest altitude of the sun is at a considerable distance from the zenith during the winter.

As to the usefulness of the spectroscope in meteorological observations, my opinion is that for the study of the distribution of water vapor in the atmosphere it is of great value, but as an instrument for regular observations upon which are to be based the predictions of future weather conditions, it is not much of an addition to the instruments already in use. It might be of considerable use at times, but hardly sufficient to justify its use at most meteorological stations. However, if a few selected stations were equipped with a simple form of instrument of sufficient dispersive power valuable data might be secured.

The increase in intensity of the water-vapor lines is quite decided upon the approach of a general storm, and depends to some extent upon the direction and the azimuth of the sun, or the direction in which the instrument is pointed in relation to the position of the storm. There is much less of a change at the approach of a local storm, and if it be a small unimportant one, the strength of the water-vapor lines may scarcely be affected at all. Neither is there any perceptible increase in the intensity of these lines when the sun is shining through clouds, or when the sunlight passes immediately underneath even a fairly large cumulus cloud. However, there is likely to be a marked diminution in the intensity of the water-vapor lines immediately after, even a small local storm, with an increase again to what it was before if the storm has been an unimportant one.

It may also be of interest to note the fact that there is a difference in the curves representing morning and afternoon observations, especially during the colder part of the year, the slopes of the morning curve being steeper, and showing relatively less water vapor in the lower regions of the air than during the afternoon. In my opinion observations made with small spectroscopes having insufficient dispersion to easily see the various lines distinctly, are worse than useless, as the region of the rain-band contains many solar lines which can not be distinguished from water-vapor lines without good definition and considerable dispersion.

The pointing of a spectroscope toward the sky, instead of the sun, will also give erroneous results of scarcely any use whatever for purposes of study.

TABLE II.—*Solar lines.*

Name of line.	Intensity, Q=1.	Wave length.	Name of line.	Intensity, Q=1.	Wave length.
D_2	4.250	5890.182	L	0.551	5916.475
A*	*	5891.4	M	0.211	5918.7
B	0.072	5892.0	N	0.288	5922.2
C	0.183	5892.9	O	0.483	5923.0
D	0.755	5893.098	P	0.391	5929.9
E	0.060	5893.4	Q	1.000	5930.410
D_1	3.145	5896.154	R^1	0.132	5933.9
F	0.320	5899.5	R	0.781	5934.883
G	0.146	5899.7	S	0.195	5941.9
H	0.197	5902.7	T	0.935	5943.761
I	0.611	5905.895	U	0.355	5949.5
I^1	0.219	5907.1	V	0.680	5952.9
J	0.355	5910.1	W	0.319	5953.3
K*	*	5914.884	X	0.571	5956.925

* Intensities of solar lines having atmospheric components:

$$A = 0.215\ Q + 0.135\ l_2$$
$$K = 1.28\ \ Q + 0.375\ l_2$$

TABLE III.—*Water-vapor lines.*

Name of line.	Intensity, $l_2=1$.	Wave length.	Name of line.	Intensity, $l_2=1$.	Wave length.
a_1	0.235	5891.7	k_4	0.205	5916.8
a_2	0.700	5891.8	l_1	0.425	5918.6
a_3	*	5892.6	l_2	1.000	5919.855
b_1	0.300	5893.2	l_3	0.413	5920.7
b_2	0.355	5893.7	m	0.500	5922.7
c_1	0.250	5894.6	n_1	0.769	5924.4
c_2	0.270	5895.1	n_2	0.535	5925.1
c_3	0.200	5895.3	o_1	0.590	5928.4
d_1	*	5898.395	o_2	0.132	5929.4
d_2	0.470	5899.1	o_3	0.085	5929.6
$e_{1,2}$	0.980	....	p_2	0.117	5930.8
e_1	0.410	5900.1	p_3	0.125	5931.1
e_2	0.620	5900.2	p_1	0.300	5932.2
f_1	*	5901.681	q	0.400	5932.9
f_2	0.300	5902.3	r_2	0.135	5935.4
g	0.570	5909.1	r_1	0.295	5936.0
h_1	0.355	5910.3	s_1	0.550	5941.8
h_2	0.500	5910.9	s_2	....	5942.6
j	0.485	5913.1	s_3	....	5942.8
k_1	0.250	5915.1	t	....	5943.4
k_2	0.230	5915.6	u	0.635	5949.5
k_3	0.225	5915.8			

* Intensities of water vapor lines having solar components:

$$a_3 = 0.070\ Q + 0.410\ l_2$$
$$d_1 = 0.030\ Q + 0.840\ l_2$$
$$f_1 = 0.050\ Q + 0.950\ l_2$$

TABLE IV.—*Mean intensity from curves representing the mean value of βm for the respective months.*

Zenith distance.	1892.							
	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.
0°	(0.160)	(0.190)	(0.210)	(0.230)	0.460	0.640	0.530	0.470
20°	(0.200)	(0.230)	0.250	0.325	0.520	0.760	0.640	0.580
45°	(0.245)	0.290	0.310	0.450	0.730	1.160	0.960	0.860
60°	0.295	0.385	0.390	0.590	1.080	1.730	1.440	1.190
70°	0.425	0.520	0.500	0.800	1.570	2.440	2.000	1.600
80°	0.780	0.850	0.800	1.330	2.450	3.680	3.150	(2.350)
85°	1.130	1.290	1.180	1.940	3.330	(4.640)	(4.350)	....
87° 30′	1.480	1.780	1.600	2.480	(4.070)	(5.300)	(5.100)	....
89°	1.920	2.400	2.080	2.980	(4.700)	....	....	....
90°	2.500	3.100	2.800	(3.400)	....	....	....	....

Zenith distance.	1892.				1893.	Intensity from curves for special dates.		Intensity of the oxygen line. a
	Sept.	Oct.	Nov.	Dec.	Jan.	Cold wave, Jan. 10, 1893.	Hot wave, July 14-18, 1893.	
0°	(0.340)	(0.320)	(0.230)	(0.170)	(0.150)	(0.070)	1.080	0.230
20°	(0.400)	(0.370)	(0.290)	(0.200)	(0.190)	(0.095)	1.220	0.250
45°	0.590	0.490	0.390	(0.280)	(0.250)	(0.125)	1.640	0.310
60°	0.900	0.690	0.520	0.370	0.320	0.160	2.180	0.360
70°	1.440	1.010	0.775	0.585	0.420	0.205	2.830	0.425
80°	2.250	1.760	1.440	1.080	0.730	0.310	3.900	0.610
85°	(2.940)	2.590	2.160	1.630	1.120	0.485	(5.000)	0.890
87° 30′	....	(3.430)	2.850	2.100	1.560	0.680	....	1.210
89°	....	(4.000)	3.600	2.600	2.080	0.940	....	1.550
90°	....	(4.700)	(4.300)	(3.300)	2.800	1.230	....	2.000

Dated, BALTIMORE, *October* 25, 1893.

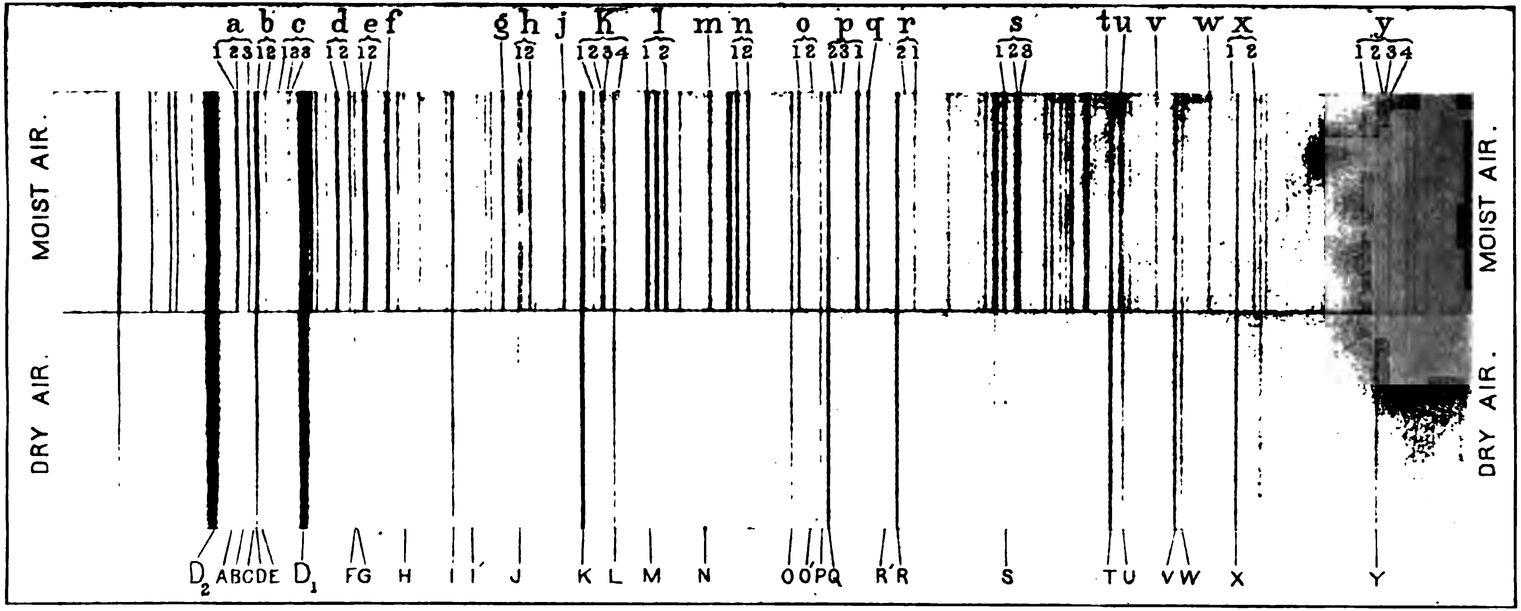
MOIST AIR.
DRY AIR.
a b c d e f g h j K l m n o p q r s t u v w x y
1 2 3 1 2 1 2 3 1 2 1 2 1 2 1 2 3 4 1 2 1 2 1 2 2 3 1 2 1 1 2 3 1 2 1 2 3 4
D2 A B C D E D1 F G H I I′ J K L M N O O′ P Q R′ R S T U V W X Y
MOIST AIR.
DRY AIR.

Fig. 1.—Spectrum of the rain band.

BULLETIN No. 17.—W. B. No. 88.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

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THE WORK

OF THE

WEATHER BUREAU

IN CONNECTION WITH THE

RIVERS OF THE UNITED STATES.

PREPARED UNDER THE DIRECTION OF

WILLIS L. MOORE,

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LETTER OF TRANSMITTAL

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., January 12, 1896.

SIR: I have the honor to transmit herewith bulletin on "The work of the Weather Bureau in connection with the rivers of the United States," and to recommend its publication as a bulletin of the Weather Bureau.

I take pleasure in acknowledging the valuable assistance rendered in the preparation of this paper by Maj. H. H. C. Dunwoody, U. S. A., assigned as assistant chief; Henry E. Williams, chief of division, and Alexander McAdie, local forecast official.

Very respectfully,
WILLIS L. MOORE,
Chief of Bureau.

HON. J. STERLING MORTON,
Secretary of Agriculture.

INTRODUCTION.

On January 1, 1896, the Weather Bureau river and flood system consisted of 135 special river stations, equipped with standard river gauges for measuring the vertical rise of the surface of the water, and in many cases with standard thermometers for measuring air temperature. These stations were manned by local observers receiving from the Weather Bureau pay commensurate with their services. There were 44 rainfall stations, equipped with rain gauges and manned by local paid observers, and so distributed in the various catchment basins of the tributaries to important rivers as to give, in connection with the regular meteorological Weather Bureau stations, a fair approximation to the average rainfall throughout each watershed. There were 38 completely equipped meteorological stations of the Weather Bureau where river measurements were made, and 22 Weather Bureau stations which were centers from which flood warnings and forecasts of expected changes in river level were issued.

The special work of the Weather Bureau in connection with the rivers of the country is to facilitate commerce on navigable streams by publishing daily information as to water stages along the course of each river, and to issue timely warnings of floods so as to effect the saving of life and property.

As yet the rules of flood forecasting are largely empirical. The official in charge of a river center is familiar with the main river and its tributaries, the area and topography of the catchment basin, the frequency and intensity of the rainfall, especially the intensity, the average time of passage of flood crest between one station and another, and the history of past rises. The knowledge of low-water conditions, especially where bars and shoals exist, is perhaps of equally great importance as the knowledge of high water. In fact, many statements are received at the central office in Washington, from steamboat and navigation companies, to the effect that low-water conditions continue longer and affect navigation more. The people living in regions contiguous to navigable streams are materially affected in their industries by the conditions of navigation, but the destruction of life and property, as affected by the rivers, depends entirely upon flood conditions. The official in charge of a river center is expected, with the data at his command, to give information to those interested in navigation, even during low or medium stages of water, that is of great pecuniary value; but his chief and foremost duty is the dissemination of warnings when floods threaten.

Many data in regard to river stages have been published by the Weather Bureau, the Mississippi River Commission, and the United States Signal Service. From the data thus collected, and now covering many years at some stations and shorter periods at others, the following general relations have been deduced: The time it takes high water to pass from Pittsburg to Wheeling is one day; from Pittsburg to Parkersburg, two days; from Parkersburg to Cincinnati, three days; from Cincinnati to Cairo, six days; from Cairo to Vicksburg, seven days, and from Vicksburg to New Orleans, four days. From Pittsburg, therefore, to the Gulf requires twenty-three days. Similar general relations concerning the movements of other rivers have been determined. Since the time of travel is so great it naturally follows that many interfering conditions arise, tending to accelerate or retard the crest of the flood wave. No simple time rules are, therefore, possible.

The volume of water passing a station in a given time is known only at a few places, and varies, of course, with high and low water. Nor can simple rules be based upon the rainfall, as the absorptive condition of the soil is not constant, and the distribution of precipitation over the drainage area is not always determinable.

The principal rivers concerned in the Weather Bureau system are the Alleghany, Monongahela, Ohio, Kanawha, Wabash, Illinois, Tennessee, Cumberland, Mississippi, Missouri, Arkansas, and Red rivers of the central valleys; the Columbia, Sacramento, and San Joaquin of the Pacific Coast; and the Hudson, Susquehanna, Potomac, Savannah, Chattahoochee, and Alabama of the Atlantic and east Gulf coasts. Gauging stations are most numerous on the rivers of the central valleys, and rainfall stations are more numerous throughout the catchment basins of these rivers than they are on the combined rivers of the Atlantic and Pacific coasts.

The river flood service of the Bureau was reorganized on July 3, 1893, and the duty of warning communities resident along the great rivers placed in the hands of local forecast officials at the principal river centers. Each forecaster in charge of a river center has a definite section of the river system of his district to watch and forecast for. He receives the necessary telegraphic reports of rainfall which has occurred over the tributaries in his river district, the daily telegraphic data as to gauge readings nearer the source of the main river than his own station, also gauge readings on many of the tributary streams. Each forecaster is familiar with the area of the catchment basin from which his rainfall reports are received, the contour and configuration of the surface, and the permeability of the soil. A slowly falling rain of considerable volume on a nearly level and permeable soil may cause little rise, while a rapidly falling rain of the same amount on an impermeable and greatly inclined surface will gather quickly in the channels of the tributaries, and soon become a rushing torrent in the main stream. The local forecasters are furnished with all the data available relative to the history of previous floods and, therefore, are equipped as completely as possible for the work before them. With such advantages, and with their own experience and ability, it is thought that no disastrous rise of the waters can occur in the future without adequate warning of the same having been given to all concerned.

A river bulletin board has been placed on some of the principal steamboats leaving Cairo, so arranged that the river stages can be read by people on shore and on passing steamers. Thus pilots ascending or descending the river get the latest readings at the places they are bound for.

The river gauge is a graduated scale on which the height of the river is measured. The zero of the gauge is usually at or somewhere near the level of the lowest water known. A gauge is generally vertical, and is usually fastened to a bridge, pier, or piling, and is of sufficient length to cover the greatest height of water likely to occur. When a river gauge can not be set vertically it is laid on the bank, according to the slope of the ground. The foot marks on a gauge of this kind must be accurately located by means of a spirit level, so as to agree with those on a vertical gauge. When a stage of water below the zero occurs it is read as a minus stage. It is not desirable to change the zero point after readings made from that basis have continued for any length of time.

It may be of interest to know that on account of the narrowness of the valley and the precipitous shore line of the Ohio the water in the river must show rises varying from 30 to 50 feet before the danger line is reached. At Cincinnati the danger line is 45 feet above the zero of the scale, and a height of 71 feet above zero has been recorded. On the Upper Mississippi the danger lines average about 15 feet above zero, but from St. Louis southward to Vicksburg they average about 35 feet, while at New Orleans, with its great system of levees, the danger limit is but 13 feet above zero.

In the early history of the river system the data received from the various river stations, though meager, were sufficient to permit useful warning of marked changes in the river levels. In the spring of 1874 this branch of the Bureau had its first experience with destructive floods. In that year floods devastated the valleys of the Lower Mississippi, the Arkansas, White, Red, and other rivers, causing crevasses in the levees and inundating large areas of bottom lands in the Mississippi Delta. The value of the special reports which were telegraphed at that time by the Weather Bureau could scarcely be determined. They were the only reports sent directly to the people of the flooded districts, and showed daily the coming rises and falls of the water. A study of these floods showed the necessity of establishing for each of the rivers a certain depth of water above which the stages were dangerous to river interests. These points were designated as "danger levels" and "danger lines," and were established for the Mississippi, Missouri, and Ohio rivers during that year. In prosecuting this work, data from the best obtainable authorities were collected and compiled for the construction of a chart of the basins and watersheds of the principal rivers. A river slate was designed, on which were outlined the average grades of the beds of the different rivers at the different parts of their courses. The object in preparing this chart was to facilitate the tracing of flood waves, and their movement from one place to another. When an unusually heavy rain was noted in any watershed, it was known into what rivers it must flow and about the amount of rise that would result. A knowledge of the rapidity with which the flood would travel and of the rivers it would pass made it possible not only to follow its course, but also to give timely warning of its approach.

Some idea of the vast destruction of property due to floods may be gathered from the statement that the floods of the spring of 1881 and of 1882 caused a loss of not less than $15,000,000 to the property interests of the Ohio and Mississippi valleys. It may also be noted that the flood of the spring of 1882 caused a loss of 138 lives in the region from Cairo southward to New Orleans.

In forecasting stages of water during such flood periods as the two mentioned, it must be borne in mind that precipitation may be only an inconsiderable factor. In those cases vast quantities of snow, which had accumulated during the winter, overlay the Northern States, and with the early rains of spring came abnormal heat, causing a very rapid melting of the snow lying over many of the watersheds. In these floods it is probable that the sudden coming of abnormally high temperatures was a more potent influence than the immediate precipitation.

The floods of 1884 began in the Ohio Valley in February, when the river reached the highest stage on record. The Mississippi River, from Cairo to the Gulf, also reached a very high stage. Ample and timely warnings were telegraphed to all available points throughout the Ohio Valley, and the resources of the Bureau were taxed to the utmost in the interests of the flooded districts. The damage caused in the Ohio Valley by this flood could hardly be calculated. In the region about Cincinnati alone the loss of property was variously estimated at from $10,000,000 to $26,000,000.

From June, 1889, to July, 1893, the care and supervision of the flood service of the Bureau were intrusted to a single individual, and a considerable extension of the system was made in the way of establishing rainfall stations near the head waters of the more important tributaries of the great rivers. In the early part of June, 1889, forecasts were made twelve to twenty-four hours in advance of the flood which reached the city of Washington, and the value of property saved in this city alone was many times greater than the annual appropriation for the entire flood service of the country.

In the spring of 1890 the Lower Mississippi Valley was flooded for a distance of 40 miles back from the river, in the States of Missouri, Arkansas, Mississippi, and Louisiana. The special flood warnings, which were amply confirmed by subsequent stages of the water, were issued from Washington in advance of the flood, and in several instances far in advance of the flood crest.

Instances are numerous, but it is not necessary here to state them, showing the vast utility, from a commercial standpoint, of a thoroughly equipped Government flood-warning system, notwithstanding the fact that the forecasts are based upon empirical reasoning and are therefore subject to more or less error. The allotment from the annual appropriation for the support of the river and flood system of the Weather Bureau is not greater than the value of property that may be saved in one of the rooms in the cellar of an ordinary commercial house.

In considering the relation of the Weather Bureau to the hydrography of the country it should not be forgotten that to-day there are about 2,000 standard rain gauges quite uniformly distributed throughout the region east of the Rocky Mountains, from which daily measurements of precipitation are received by mail at the central office each month. In the Rocky Mountain and Pacific Coast region about 1,000 gauges are placed, but on account of the paucity of population there are many important regions from which proper data are not being received. Especially for the purposes of irrigation, measurements of snowfall on the high mountain ranges are valuable, but the present distribution of observation stations is inadequate to properly record the conditions.

WILLIS L. MOORE,
Chief of Weather Bureau.

WASHINGTON, D. C., *January 12, 1896.*

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RIVER FLOOD SERVICE OF THE UNITED STATES.

RIVER REPORTS AND FLOOD WARNINGS.

THE WEATHER BUREAU AND RIVER FLOODS.

Prior to 1873 observations of river stages were made at a limited number of points by the United States Engineer Corps, and at some of the more important river ports regular readings of the height of the water were taken under the direction of the municipal authorities. In that year the work of making daily observations of the height of the water in the rivers was formally begun by the Weather Bureau, and the water stage at each station of observation on the principal rivers was telegraphed with the weather report daily to other river stations, where the various readings were bulletined and published in the daily press for the information of all concerned. At the central office at Washington the telegraphic reports were used for determining changes in the stage of the several rivers for the benefit of river commerce and for forecasting the occurrence of destructive floods. The stage of the water reported usually indicated the height of the water above low water mark, and in places where the water has since fallen below the zero of the gauge so determined no changes have, as a rule, been made in the elevation of the gauge. When, therefore, the water has fallen below the zero of the gauge so established, the readings have been reported as — (minus) and have indicated the distance of the water surface below the zero mark on the gauge.

The gauges used have not conformed to any standard pattern. Some have been constructed by the Government and some by the cities in which they are located. At many points they have been marked on the piers of bridges, or are composed of stones or timbers laid along the incline of the river bank. A necessary feature of the gauges has been that their construction would permit of accurate readings of the vertical height of the water surface above the zero of the gauge.

River notes were first regularly incorporated in the Monthly Weather Review in May, 1873, and consisted of a summary of the more important changes in the water stages of the larger rivers. Since that time the Review has presented a monthly history of the water fluctuations and floods of the principal waterways of the country. The chapter devoted to rivers has also contained notes bearing upon inland navigation both upon the rivers and the Great Lakes, and forms a record of the dates of closing of navigation by ice and low stages of water, and of the dates upon which navigation has been resumed.

In addition to reports of the water stages, daily observations of surface and bottom water temperatures of the rivers and lakes and on the seacoast were made for the use of the United States Commissioner of Fish and Fisheries, the object being to determine the proper rivers and lakes in which to place the different varieties of food-fish. Announcements of probable approaching changes in temperature calculated to cause the freezing or opening of canals were also sent to those interested in canal navigation.

In the following year a circular dated March 25 was issued which showed the range between high and low water marks on the Western rivers, and the height at which rises became dangerous along their banks. This was said to have been the first systematic attempt to establish a danger line on those rivers. This circular elicited correspondence which contained much additional valuable information concerning the rivers, which was utilized in the current work of the office and incorporated in subsequent published river statistics.

In 1877 steps were taken to extend the plan of river reports to the rivers of California and Oregon with a view to forecasting rapid rises and falls, which involved grazing, agricultural, and commercial interests, and in the following year river reporting stations were established at a number of points in those States. In 1880 arrangements were made for the construction of gauges and the transmission of telegraphic river reports at points on the Rio Grande River. In that year 23 special river stations, exclusive of the regular stations of the Bureau, were in operation on the rivers east of the Rocky Mountains, and 6 special river stations had been established in California and Oregon.

The second important flood in the history of the Weather Bureau occurred in the spring of 1880, when many of the streams of the Southern States rose above the danger line. At Cairo the Mississippi passed the danger line March 9, and reached 44 feet 7 inches, 4 feet 7 inches above the danger line from the 21st to the 25th, and fell below the danger line on the 30th. At Memphis the danger line was reached on the 18th, and the water continued slightly above that point during the balance of the month. At Vicksburg the danger line (41 feet) was reached on the 11th, and the stage of water increased to 42 feet 11 inches at the close of the month. The water at New Orleans reached the danger line on the 10th, and the maximum stage, 13 inches above the danger line, was reported on the 28th. Although several crevasses occurred in the Lower Mississippi levees, little damage was caused during the month of March in that region. At Cairo, however, about one-fourth of the city was flooded to a depth of 3 to 5 feet. High water also caused some damage along the Tennessee, Cumberland, Alabama, and Chattahoochee rivers. These freshets resulted from very heavy rains in the Southern States, and in the basins of the Cumberland and Tennessee rivers. The Mississippi River continued above the danger line from Vicksburg to the Gulf during the following month of April. A number of breaks occurred in the levees of the Lower Mississippi and tributaries, causing considerable damage to farming lands, drowning stock, and interrupting traffic. Floods also occurred in the rivers of California in April. The Lower Mississippi gradually subsided below the danger line during the last half of May, after having been at flood height during a period of about ten weeks. The information previously collected and collated relative to the rivers of the flooded districts made it possible to foresee the sweep of the flood tides from their origin in the rain-deluged mountain districts of the Southern States and Tennessee along their southern course to the Gulf, and in the case of the Cumberland and Tennessee to their junction with the Lower Ohio, and to calculate their velocity along the Lower Ohio and Lower Mississippi. These tides were supplemented by heavy rains along the courses of the rivers, and previous study of the influence of copious rains in the watersheds of the different streams allowed a just estimate to be made of the effect of these rains upon the water stages, and permitted timely information and warnings by telegraph to the threatened sections.

In June, 1881, the work of revising the circular of information regarding rivers was begun, the new edition to include new data contained in replies to a letter of inquiry that had been sent to all observers. In February, 1881, destructive floods occurred along many of the rivers of the country. The following comments on these floods in the Monthly Weather Review are interesting: "It becomes necessary to note one of the most important features of the month, and in connection therewith to consider two predominating influences in the production of remarkably serious consequences that have resulted in a vast destruction of property, the counterpart of which has not transpired in some sections for twenty years. These two causative elements have been confined to different periods of the month and widely separated portions of the country. The first, a result of excessive precipitation, was experienced throughout the Pacific Coast and northern plateau regions and along the west Gulf Coast between the 1st and 6th; the second, due to continued high temperature, the maximum of the month, operated throughout the Ohio Valley and the Middle States, in northern Ohio and Indiana, from the 10th to the 16th, suddenly releasing the ice-bound rivers and converting the huge snowdrifts into torrents of water." Destructive floods continued throughout the great central valleys and the Southern States during March, 1881. The Mississippi River rose 10 to 11 inches above the danger line from Cairo to the Gulf, the Ohio continued high, and the Savannah River at Augusta rose to 32 feet 4 inches, the highest point since 1865. The Mississippi and Missouri rivers maintained dangerous heights during

April. The Monthly Weather Review contained the following general reference to these floods:

"This subject assumes more than usual interest during the present month (April), because of the unprecedented loss of life and property, and, not least, the extreme height to which the water rose during the prevalence of the flood. In connection herewith, as presenting some of the probable causes which were at work in the production of this great calamity other than the immediate influence of the breaking up of ice, it will be well to note that in the Northwest, up to about the 12th, snow was on the ground to a depth of 15 to 50 inches, the accumulation of almost the entire winter, and in the Upper Mississippi Valley as far south as Burlington, Iowa, it varied from 3 to 5 feet. In this connection it will be of interest to recall the fact that during the month of March, just past, these regions were subjected to the heaviest snowstorms experienced, in many instances, for a period of twenty-five years. With this remarkable accumulation of snow there appeared the preserving concomitant of very low temperatures, for, as records will show, the mean temperature for March throughout the Upper Mississippi and Missouri valleys was 1.4° to 3.1° below the normal, a very important factor, and tending materially to prevent the gradual and therefore harmless disappearance of the large mass of snow. Further, it will be remembered that during the past winter ice formed in the Western rivers to a thickness and extent, in several instances, never before realized. With these conditions precedent the month of April opened with occasional heavy falls of snow and low temperatures, the minimum of the month, which ranged from —14 to +18, occurring between the 1st and 12th. Following this the temperature rose slowly until the 20th, after which the change was more rapid, reaching the maximum of the month between the 22d and the 26th. It would seem that in the above we have an epitome of the principal forces incident to the remarkable floods of April, 1881. Roughly estimated, but, nevertheless, said to be underrated rather than exaggerated, the loss in property has been placed in money value at the following figures: Over the territory from British America southward to the latitude of Sioux City, Iowa, $3,500,000; from Sioux City to the latitude of St. Louis, $2,500,000." In June, 1881, heavy rain caused destructive floods about the head waters of the Ohio River.

The destructive floods in the Lower Mississippi Valley of the spring of 1882 were made the subject of Signal Service Notes No. XV. The data upon which this paper was based were obtained through forms containing a set of seventeen questions relative to the floods which, with letters of transmittal, were widely distributed throughout the flooded districts. Three hundred and seventy-two persons filled in and returned these forms. In addition to the data so obtained the records of 22 regular Weather Bureau and 57 volunteer river observers and 15 river stations in the Mississippi, Missouri, and Ohio valleys were used, The tables prepared showed that the floods of 1882 continued longer and were of greater depth than those of any year since 1873. In looking into the causes of floods, tables were prepared which indicated the relation between the floods of the various rivers and precipitation in the several watersheds, and the effect of melting snow upon the stages of the several rivers. The various conditions which appeared to favor and cause floods were also summarized. The estimated loss of life in the Mississippi Valley south of Cairo during this flood was 138 persons, and the loss to property was placed at $9,655,000.

The floods of 1883 began in February, and caused the greatest damage in that month in the Ohio Valley. In the Lower Mississippi Valley the river did not attain its greatest height in February, although the water was above the danger line as far south as Vicksburg. The flood continued in the Lower Mississippi Valley during March, and although less destructive than in 1882, caused loss of life and great damage to property, especially in Arkansas.

The system of river reports was greatly extended during 1884, a special appropriation having been made for that purpose. The floods of 1884 began in the Ohio Valley in February, when the river reached the highest stages on record, and inundated cities, towns, and large areas of country, causing immense loss of property. The Mississippi River from Cairo to the Gulf reached a higher stage than in February, 1883. Ample and timely warnings were telegraphed to all available points throughout the Ohio Valley, and the resources of the Bureau were taxed to the utmost in the interests of the flooded districts. The damage caused in the Ohio Valley by this flood could hardly be approximated. In the region about Cincinnati alone the loss to property was variously estimated at $10,000,000 to $25,000,000. The flood continued in the Lower Mississippi Valley during March, and the water at New Orleans exceeded by 1 inch the high stages of 1873 and 1883. Destructive floods also occurred in California in that month. In November, 1884, special instructions were issued for the guidance of river observers in erecting gauges, taking observations, rendering reports, etc., and on January 1, 1885, the special river stations were arranged in sections and placed in charge of Weather Bureau observers at section centers. These centers were usually located at some important city, where the river reports in the vicinity could be readily collected for the benefit of the river interests. On that date the measurement of the depth of water was changed from feet and inches to feet and tenths of a foot. During the year ending June 30, 1885, 25 new river stations were established, giving a total of 62 special stations in addition to the regular reporting stations of the Bureau. The special study which had been pursued by the aid of the excellent and growing river service led to a determination of the rate of travel of freshet waves in rivers furnished with reporting stations, and enabled the central office to issue special bulletins containing timely warnings of the approach of dangerously high stages of the water in the several rivers. A number of cases are cited in the annual reports in which the estimated value of property actually saved by these warnings aggregated hundreds of thousands of dollars.

In the following year there were 68 paid special river stations in operation, and during 1887 this number was maintained. The disastrous floods which had occurred during the preceding few years prompted additional and careful study of the river-flood problem. This study was made with a view to a more accurate determination of the extent and continuance of great floods many days in advance, and was directed more especially to the condition of the earth when heavy rains occurred, the amount of rain, and the average loss of water by evaporation and absorption. With a view of improving the river service, all the important river gauges were visited in that year, their zeros carefully determined, and every precaution taken to insure the greatest possible accuracy in the river observations. A system of rainfall stations was also arranged from July 1, 1887. These stations were carefully located at suitable points in the great watersheds of the country near the sources of the principal tributaries of the larger rivers. The observers at these stations were paid a nominal sum daily for their reports, which were mailed weekly to designated centers, and in case of heavy and excessive rainfall this information was transmitted by telegraph to a designated Weather Bureau station, in order that the information might be promptly used for the preparation and distribution of such warnings or forecasts as the judgment of the observer or forecast official might dictate. Owing to a lack of funds, the river reports were discontinued during a portion of 1887. When, however, the stage of water in the Lower Ohio and Mississippi rivers became dangerous, the numerous and urgent requests for a continuance of the reports made manifest their great importance, and they were resumed at the expense of other important work until the floods subsided.

No marked changes were made in the system of river observations during 1888. The principal floods of the year were noted as follows: In May a destructive flood prevailed in the Upper Mississippi River, causing great loss of property in the cities and towns along its banks in the States of Minnesota, Wisconsin, Iowa, Missouri, and Illinois. In July heavy rain caused destructive freshets in the Upper Ohio River and tributaries, and in streams of the Alleghany Mountain districts. During August destructive freshets, due to heavy rains, occurred in many portions of the Southern States. Floods inundated lowlands and caused great damage to the cotton crop in the south Atlantic and east Gulf States in August, 1888.

On June 1, 1889, the care and supervision of the river and flood service of the Bureau was intrusted to a single official. Prior to that time the responsibility for the maintenance of the river stations and the prediction of the stages of the water was divided between three different divisions. At that time observations of the height of rivers were made at 70 places on 26 rivers. At many of the more important points these observations were continued throughout the year; at other points they were made weekly, excepting during the months in which floods were likely to occur, when the stages were telegraphed daily to Washington and to section centers. The river stations were supplemented by 45 rainfall stations, located near the head waters of the more important tributaries of the great rivers; from these stations rainfalls of 1 inch or more in twenty-four hours were telegraphed to section centers. On July 1, 1889, the time of making the river-stage observations was changed from 2 p. m. to 8 a. m. This change was made in order that the observations could appear in the afternoon press; by the former method, the reports were issued too late for the evening papers. In addition to the regular 8 a. m. observations, readings were made at 5 p. m. daily, for the benefit of the morning papers.

In the latter part of May and the early days of June of this year very destructive floods occurred in Pennsylvania, Maryland, western New York, and West Virginia. In connection with these floods, forecasts, based upon general meteorological conditions, were made twelve to twenty-four hours in advance, and while the value of property saved by these warnings in Washington City alone was far greater than the annual appropriation for the entire flood service of the country, yet had money been available for the placing and maintenance of proper gauges and rainfall stations the forecasts could have been made with greater exactness and been the means of saving a much greater amount of property. In 1889 the State of South Carolina established a number of river stations to be under the control of its State weather service. Additional investigations were carried on during that year by the Weather Bureau, which considered the rainfall over the entire watershed of the Mississippi River and its tributaries, the possible evaporation, the amount of water the saturated air could contain, the quantity of water which is held in the soil and given out as a perennial flow, and that which drains into the sea.

In the spring of 1890 the Lower Mississippi Valley was visited by one of the most disastrous floods ever experienced in that region, and along the lower course of the river the water rose 1 to 2 feet higher than the highest stages previously recorded. Although extended lengths of the levees had been recently repaired, strengthened, and raised under the direction of the Mississippi River Commission, much of the newly constructed work was unable to withstand the long-continued pressure and wash of the water, and, after flood conditions had continued nearly a month, the levees began to give way at many points, flooding the country for a distance of 40 miles back from the river in the States of Missouri, Arkansas, Mississippi, and Louisiana. Special river bulletins and flood warnings, which were amply confirmed by subsequent stages of the water, were issued from Washington in advance of the destructive floods, and in several instances far in advance of the flood crests.

During the following year observations of river stages were made at 27 regular Weather Bureau stations and 109 special river stations, and these were supplemented by 50 rainfall stations. Thirty-eight river stations were established during the year, a majority being located in the Southeastern States for the benefit of the interests along the Alabama, Coosa, Tallapoosa, and other rivers in that section. During the Ohio and Mississippi valleys floods of the early part of the year, bulletins showing the daily stages and changes and containing definite predictions for several days in advance were widely distributed throughout the sections interested. A report was also issued, entitled "Practical rules for the prediction of flood stages of rivers in the United States." The publication of the stages of the principal rivers of the United States, previously begun, was continued, and three parts of this compilation were completed, i. e.:

"I. Stages of the Ohio River and its principal tributaries, 1858 to 1889, inclusive." "II. Stages of the Mississippi River and its principal tributaries, except the Ohio River, 1860 to 1889." "III. Stages of miscellaneous river stations in California, Oregon, North Carolina," etc. These volumes show all the river stages observed by the Weather Bureau up to January 1, 1890, except for places where the stages had already been printed by the Mississippi River Commission.

In 1892 8 a. m. river observations were made daily at 191 stations; at a number of these stations, however, the readings were taken only during the months in which high water was likely to occur. Records of these stages were preserved and printed by the Weather Bureau, and records of stages taken at other points on the principal rivers were printed by the Mississippi and Missouri River Commissions. The Annual Report of the Chief of the Weather Bureau for 1891–92 contains tables giving the following classes of data relating to the navigable rivers of the country:

Table I gives the river discharge, or quantity of water passing a place in cubic feet per second, at high and low water at a few places for which the amount has been determined.

Table II gives some of the principal information in regard to the Weather Bureau stations, as follows: (1) River station and river on which situated; (2) year of beginning of observation; (3) number of years of observation; (4) drainage area above place in square miles; (5) height of zero of gauge in feet above sea level; (6) height of flood line above zero of gauge in feet; (7) average number of days annually above flood line; (8) greatest number of days above flood line in a year and the year; (9) highest water and date; (10) average of annual highest waters; (11) average number of days annually above average highest water; (12) average date of highest water; (13) lowest water; (14) average of annual lowest waters; (15) average number of days annually below average lowest water; (16) greatest number of days below average lowest water, and the year; (17) average date of lowest water.

Table III contains mean stages of rivers for months, years, and for five and ten year periods at places where there was a sufficiently long record. Plates were also published giving the curves of river stages, or composite hydrographs, at a number of places for which there were long records.

No further marked changes were made in the system of river observations and forecasts until July 1, 1893, when the immediate supervision of the river service and the predicting of river changes for their several districts was delegated to the various local forecast officials of the Bureau. This duty has been satisfactorily performed by these officials since that date, under the general supervision of the central office at Washington.

In order to determine the value of the work of the river and flood service in the various sections of the country during the last two years, a circular letter was addressed to certain observers of the Weather Bureau, directing them to forward to this office within a week a brief statement showing the particular interests in their communities most affected by river conditions. Also an estimate of the value of the warnings of floods and high water, and all instances within the past two years where the success of the warnings has been marked.

VALUE OF THE RIVER AND FLOOD SERVICE.

The following reports were rendered in response to the foregoing directions:

ATLANTA, GA.

There are no interests whatever in this community affected by river conditions, the nearest stream, the Chattahoochee, being 8 miles distant. At Rome, in the northwest portion of the State, every business interest in the city is vitally affected by the rivers. Occupying a narrow, V-shaped peninsula between and just at the point of intersection of the Oostenaula and Etowah rivers, two streams that flow with remarkable rapidity from their mountain sources, it is so dangerously situated, that it appears incredible that a city should have been built at such a place. Rains lasting two or three days, and aggregating from 5 to 7 inches, at Rome and at points above on the Oostenaula and Etowah, will send the Coosa River at Rome from the zero of the gauge to above the danger line within forty hours or less time; and as there is not a house in the city used for business purposes that has not been flooded from 1 to 15 feet, it is no exaggeration to say that the value of reliable flood warnings is incalculable, all merchants being constantly prepared at short notice to move their wares and other property to the upper stories of their buildings. The cost of such moves is, however, considerable, not to mention the damage by handling, breakage, etc.; consequently the next most injurious thing to the flood itself is the false warning of one. Recently, while in Rome for the purpose of getting a better idea of the river conditions there, leading citizens informed me that should a flood come suddenly and without warning upon them, the loss would exceed $1,000,000 and probably amount to as much as $2,000,000. Though there has been much uneasiness at times, the water has not reached the danger line at Rome during the past two years. The last floods occurred in January and April, 1892, previous to both of which timely warnings averted great loss to merchants, manufacturers, and other business interests. Above Rome, on both the Oostenaula and Etowah, farming lands are often badly washed just before planting time, after all preparations have been completed for a new crop, but as the most disastrous floods occur during the late winter and early spring, the damage to growing crops is not often very great. I should also mention that the railroads entering Rome suffer great damage by washing of embankments, etc.

Along the streams south of this station, the Chattahoochee, Flint, Ocmulgee, Oconee, and Altamaha, the interests affected by river conditions are largely of an agricultural character, though unusually high waters occasionally prevent steamboats from passing under bridges on the Chattahoochee, and also interrupt milling operations on the same stream. Should freshets occur about harvest time warnings would enable farmers to save at least a portion of their crops, but occurring at other times the only benefit they derive is in saving their live stock by driving them to safe places. There are lumbermen and sawmill owners on all these rivers who are greatly benefited at all seasons by the warnings, but to what extent it is impossible to estimate. The only warnings ever sent from this office, so far as the records show, were those I issued on the 14th and 15th of last March, and another issued from your office on March 20. River observers on the Chattahoochee, Flint, Ocmulgee, and Oconee rivers all write that those warnings enabled farmers to save live stock that otherwise would have perished. At Macon, on the Ocmulgee River, the warnings were published in the papers, and caused a number of families to move from the bottom lands near that city, which were soon after their departure under several feet of water. (I sent a telegram to Macon the morning of March 16, notifying them that the river would reach the danger line by the morning of the 17th.)

AUGUSTA, GA.

For a distance of about 20 miles below the city a number of farms are in operation in the river bottom which produce chiefly corn and hay, and the yield of both in favorable seasons, from April to November, is very large, provided the river stage does not pass beyond 22 or 23 feet. The river warnings are communicated at once to the owners of these farms, and also to the superintendent of the Port Royal and Augusta Railroad, whose tracks follow close to the river on the Carolina side for a distance of about 60 miles. This road, through its telegraph and train service, willingly and promptly sends the warnings out, and has implicit confidence in the river service of the station. Very little trouble was experienced from high water in 1893. On October 9, 1894, a river warning was issued at 11 a. m., when the gauge measurement was 6.2 feet, stating that the water would reach 30 feet; on the night of the following day it had reached its highest point, 28 feet. The estimated value of corn and hay saved by this warning was $1,100. On December 12, 1894, at 10 a. m., a prediction was made that the river, which then stood at 10.1 feet, would go to 26 feet on the following day. The height of this rise was 26.3 feet, but as all crops had been gathered, no special harm was done, and the benefit was confined to those who drove their stock to the high grounds. On January 9, 1895, at 10 a. m., a special notice was sent advising the community of a 30-foot river stage within the ensuing thirty-six hours, the stage at that time being 11.9 feet. The city engineer had all sewer gates opening into the river closed, in order to prevent them from bursting when the high water should arrive, and large droves of hogs which were being wintered in the bottom lands were removed to safer grounds without loss. The height of this rise was 30.4 feet.

CAIRO, ILL.

To enumerate the interests affected by river conditions in this vicinity would be to name every branch of business and industry carried on here and along the rivers.

Those most directly injured by floods and extreme low water are, first, the farmers, and, second, the steamboat and river transportation interests. As the river approaches the high-water mark, against all stages below which most of the towns and cities are now protected by levees, the anxiety and fear of financial loss increase, and the interest manifested in obtaining river news becomes intense in all classes, both in the country and city districts. It may be said that whatever conditions affect the steamboat or river transportation interests at any season of the year affect also, to a greater or less degree, the interests of producers, shippers, manufacturers, and dealers. Steamboat traffic is carried on below Cairo throughout the year, but the logging interests on its tributaries, the Obion, Forked Deer, and Hatchie Rivers, and the several bayous and creeks, are dependent upon stages of 25 feet and above on the Cairo gauge for the floating of their stock. Consequently all labor interests are favorably affected by rises when the stage is between 25 feet and the danger line.

The issue of the daily river forecasts at this station for the Ohio River from Evansville to Cairo, and for the Mississippi River from below St. Louis to Memphis, began November 16, 1893. Since that date the highest water has been 37 feet, or 3 feet below the danger line.

CHARLESTON, S. C.

Sudden and unheralded rises in the streams of this section cause great loss of live stock in the lowlands. The warnings of the Bureau have been the means of saving much stock. Steamboat men utilize the reports from the upper streams in forming opinions as to the available depth of water for navigation purposes, and the South Carolina Steamboat Company has frequently acknowledged its indebtedness to the Bureau for valuable information concerning the stage of water in the rivers of the State. The Santee, Great Pedee, and Waccamaw Steamboat and Transportation companies are also greatly interested in navigation on the Santee, Black, Great Pedee, Little Pedee, Wateree, Congaree, and Waccamaw rivers. Immense quantities of tar, rosin, turpentine, lumber, cotton, rice, and other commodities are transported over these streams annually, and it frequently happens that an entire month's output of tar, rosin, turpentine, and lumber must be removed within a short period in order to take advantage of a rise sufficient to transport these goods by water. These rises appear, usually, in the upper streams several days in advance, and the Bureau reports give considerable time in which to prepare for the rise. It is estimated that $35,000 has been saved to the steamboat men alone by these reports, and in August, 1893, one timely warning saved property valued at more than $6,000 on the Santee River. The Sea Island cotton interests suffer considerably from high water and storm tides. This particular growth of cotton is raised to some extent along streams close to the ocean. When flooded, it loses its flexibility, the staple becomes yellow, and the plant soon dies. The cutting and rafting of lumber and logs is one of the important industries, and high stages of water are necessary to float this material to the sawmills; and during the periods of high water in August, September, and October, 1894, mill men were enabled to float large quantities of logs and cut timber by the aid of the warnings and forecasts of the Bureau. One lumber firm estimates that the river reports provide the means of saving them $10,000 a year. The officers of the United States Engineer Corps state that they are greatly aided in their dredging operations in the various streams of the State by the reports and forecasts of the Bureau.

The flood and storm-tide warnings of August 27, 1893, saved property to the amount of $350,000 along the South Carolina coast. The warning of heavy rains, floods, and unusually high tides sent out September 25, 1894, resulted in the saving of an immense amount of property. In the storm of October 9, 1894, a majority of the rice planters saved 10 per cent of their stacked rice from the storm tides, the estimated value of the rice saved by the warnings being $65,000. The daily telegraphed stages of the water, especially the report from Augusta, are of great value to rice growers.

CHATTANOOGA, TENN.

The interests most affected by the conditions of the Tennessee River are those connected with steamboat and lumber interests. No dangerous stages of water have occurred during the last two years. The high water of previous years caused a great demand for the river and flood reports and forecasts. Lumber and logging interests are affected by the varying stages of the water, and, together with other river industries, derive great and constant benefit from the river stage reports and the forecasts. If this service were abandoned by the Government it would have to be continued, at heavy expense, by the community. The value of the interests on the Tennessee River at Chattanooga, and on the various tributaries which are directly affected by the river conditions, exceeds $900,000.

CINCINNATI, OHIO.

The particular interests in this community most affected by river conditions are those of the steamboat and barge men, the coal dealers, the railroads, the merchants on the lower levels, and the gardeners in valleys in and adjacent to the city.

No estimate of the value of the warnings of floods and high water, in dollars and cents, can be given, as no data can be obtained. Excepting the frozen river during the past winter, the breaking up of which was a great standing menace, no special danger in connection with the river was encountered in the past few years. In this case the river opened so gradually and quietly, by reason of the favorable weather, that comparatively little loss was experienced. I can find no statistics of any savings or loss by high waters within the past few years. The river service is deemed invaluable, and all interested are on the alert, so that all danger of damage from rising waters is averted by reason of the timely warnings and the facilities for guarding against impending danger. It is freely admitted that no money would be a recompense for the deprivation of the Government reports of rivers and rainfall.

COLUMBIA, S. C.

The Congaree River is formed by the confluence of the Broad and Saluda rivers at Columbia. These streams have a drainage area of about 8,000 square miles in South Carolina. The topography of the section drained is broken and hilly, the slopes of the hills are steep and denuded of their original covering of forest growth, and rainfall is quickly collected and drained into the rivers, causing rapid rises even with a moderate rain. The valleys of the rivers above Columbia have very little agricultural or other value. Below Columbia the valley of the Congaree widens rapidly, and includes many thousands of acres of exceedingly fertile land on which valuable crops are subject to the overflow of the Congaree. The principal crops are hay, corn, oats, and cotton, and the land not under cultivation affords pasturage for stock. Since 1890 the Congaree has risen to or above the danger line four times, and in each case the crops were greatly damaged or completely destroyed. It has been exceedingly difficult to get definite information regarding the value of the crops lost, for the reason that owners of land in the valley refuse to discuss the subject, believing that to do so would tend to depreciate the value of the land, or rather affect its market value. There has been no attempt made to predict floods for the Congaree Valley, and the value of the warnings, if issued, would be questionable, owing to the nature of the interests affected, for it would be obviously impossible to remove growing crops, or to gather ripe crops, after the danger became imminent. Stock on lowlands could, however, be removed to places of safety. Careful inquiry has failed to discover that there has ever been any serious loss of live stock by a sudden rise or overflow of the Congaree. The lower valley is principally heavily wooded swamp land, and warnings to that part of the valley would be useful to lumbering interests. The subject of warnings of floods for the Congaree Valley has been a matter for discussion among landowners in the valley and this office for the past year, the object being to devise some quick, sure, and cheap method of warnings that would reach the majority of interested people, but as yet no plan has been proposed that is considered at all practicable or feasible.

DAVENPORT, IOWA.

The interests most affected by the river conditions of the Upper Mississippi River and tributaries in the Davenport district are the Upper Mississippi improvement under the direction and charge of the United States engineers, steamboating, general navigation, rafting, and logging; and, in case of very high water, farmers cultivating lands on islands and low bottoms, and city wharfage and levees. During the summer and fall months the United States engineers are carrying on works and improvements in the river to the amount of a million of dollars or more, and reports of river stages and warnings of any sudden rise in the river are of immense value to them in successfully conducting operations. One or two instances occurred during the past season, when the warnings no doubt saved several thousand dollars' damage in this direction alone. There have been no very dangerous floods or high waters in the Upper Mississippi during the last two years. The river has reached the danger line at two stations only in the Davenport district since the station was established as a center. These were at La Crosse and Dubuque in May, 1894. Timely warnings were telegraphed on both occasions one to two days in advance of the predicted stage, and were accurately verified in each instance. Rafting companies claim that the river reports and warnings last spring were worth $10,000 to $20,000 to them, and that all predicted rises during navigation and log-rafting season, even though the rise is small when the river is low, are of vast importance and value.

FORT SMITH, ARK.

Farmers, stock raisers, lumbermen, and steamboat men are affected by the river conditions. There is no recent data on record whereby the value of property saved by flood warnings in the last two years can be estimated. From inquiries instituted by the observer there is found to be a consensus of opinion that the warnings have been of great public benefit. Extensive landowners and cultivators along the river bottoms in the Cherokee Nation have been greatly benefited by the warnings. Since May, 1893, there has been no damage by flood in this section, nor water high enough to warrant any special or general warnings. All parties interested agree as to the great advantage of being notified of dangerous and rapid rises in the river.

HANNIBAL, MO.

No flood warnings have been received since the establishment of this station. The agricultural interests are the principal ones affected by flood in this section. Across the river from Hannibal there are over 110 acres of cultivated land protected by a levee which will stand a stage of 21 feet, and warnings of a rise above that point would be of great value. On the west side of the Mississippi, commencing about 3 miles above Hannibal and extending 20 miles along the river to Lagrange, is a tract of fine farming land unprotected by levee which will stand a 13-foot stage of water without inundation. If warnings of a rise above that stage could be given a few days in advance they would be of great value to the farmers.

HARRISBURG, PA.

Ordinary rises in the Susquehanna, particularly on the west and north branches, are useful in floating logs and timber. When excessive floods are expected the lumbermen can hold their logs in the upper streams and avoid the risk of losing them in the main river. In the case of severe floods all interests in the submerged portions of the valleys would profit by the warnings. Owing to the heavy losses caused by the flood of 1889 great care must be observed in making flood warnings and forecasts, as great expense would attend the moving of goods and property which such a forecast would cause. Railroads, as well as the lumber, commercial, and agricultural interests, would also profit greatly by flood warnings, as it would enable them to remove cars containing valuable freight to safe places, load bridges, etc. Accurate forecasts of coming stages would dictate the action necessary to protect their property. Several of the towns along the two branches have been considering the plan of protecting themselves from inundation by the construction of dikes. Sunbury built a dike last summer, which is 2 feet above the highest flood. If this dike is ever overflowed they will be worse off than before, so a timely warning would be of great value in that locality. If the forecast was for a height but a little higher than this dike, it would be quite possible to raise it enough in twelve hours to protect the town. In 1889 the river service had not been organized on its present basis, and I feel confident if warnings had been then issued along the west branch of the Susquehanna for a flood 5 to 7 feet higher than that of 1865 hundreds of thousands of dollars would have been saved. I also believe that if careful observations are taken of the effect of rainfall on the river for the next four or five years floods can be predicted within a foot; and with that end in view the Pennsylvania Railroad will soon have completed several river gauges along the Juniata River, where they have also promised to have rain gauges placed (these to be furnished by this Bureau), and their employees will take observations and make reports to this office without expense to this Department. The Northern Central has also promised to cooperate along the two branches, and I am now waiting for them to designate the points where rain gauges can be placed. There are many conditions that enter into the problem in the lower districts—the season of the year, whether the crops are in the ground and the trees in foliage, the ground frozen or soft, covered with snow or bare, the depth of snow, and temperature.

During the flood of May 21 and 22, 1894, warnings were sent in every direction by telephone and railroad telegraph. This information was sent out the night of the 20th of May and early the morning of the 21st. The river reached its highest point, 25 feet 9 inches—within 14 inches of the flood of 1889—at 6 a. m. of the 22d flooding cellars and destroying all truck crops on the many islands in the river, and causing a few washouts on the railroads. Estimate of property and live stock saved by the warnings, $60,000 to $70,000.

HELENA, ARK.

I have recommended to the Department that the discharge of the tributaries or main rivers should be measured, so that an approximate could be made of the discharge at every stage, and by noticing the effect at Cairo and below we could soon tell some days in advance the probable effect of every rise. This measurement would not have to be made every year; but once or twice would give the discharge, say for each foot on the gauge. To illustrate: the Missouri River might be gauged or marked at Kansas City, the Ohio at Louisville, the Cumberland at Nashville, the Tennessee at Chattanooga, and the Mississippi at St. Louis. Minor streams like the Wabash could be gauged also. The measurements need not be at the points designated, but at such points as they could be done most accurately, owing to the conditions of the banks, etc. With all this knowledge, great experience and knowledge of other conditions would be required to make the proper forecasts. A sudden or a slow rise would have to be considered; also the condition and extent of the levees. It requires twelve to seventeen days for a rise to reach Helena from Cairo, with the St. Francis swamp not leveed. A levee is being built which, when completed, will bring the rise from Cairo to Helena in less than four days. This levee is partially constructed, and I can not tell what effect it will have on the rise here, but will have to wait and see. According to my notion, this levee will raise the water along the St. Francis point from but little at Point Pleasant, Mo. (the head of the levee), up to 8 to 12 feet at Memphis. As this levee is being built only 3 to 4 feet above the present high-water mark, it will take several high waters before it will be built to that height, and it may be abandoned as impracticable before that time. As to the effect at Helena and below, it would be but little, under certain circumstances, except to bring the river to the highest point in four days instead of seventeen. It would make a great difference at Helena should there be a sudden rise and fall at Cairo, or whether the rise was slow and the river stood at or near the highest point and then fell rapidly. With the levee completed, it would make but little difference, as the whole volume of water would be forced down the channel, instead of losing an immense amount in filling the reservoir of the St. Francis swamp.

KANSAS CITY, MO.

There are no interests of note affected by the river conditions until the river reaches the danger line. This stage has been reached but five times since 1873—the period covered by the records of this office. When the stage of water is near the danger line there is, of course, more or less apprehension lest it should continue to rise. There is no navigation on the river at this place. The interests affected by floods are in the village of Harlem, just opposite this city, some implement and wholesale houses, the packing houses in the west bottoms, and the probable washing away of railroad tracks on the river bank.

No river warnings were furnished this station previous to last summer, when the official at Omaha sent them for a month or so while the water was within a foot or two of the danger line. Previous to that time local forecasts were made and given to the public from day to day when the river approached a dangerous stage. It is impossible to place a money estimate upon the benefits that may have been derived from the warnings. The parties interested took precautionary measures against encroachment by the rising waters, but just what would have been the result had no forecasts been made public is of too doubtful a character for an estimate. No special benefits have been derived from warnings during the last two years. Some of the packing houses have asked for an opinion regarding the probable outlook for the season of high water, but it is not known to what extent they builded upon the information received.

KEOKUK, IOWA.

The river conditions are locally of most importance to lumbermen and lumber dealers, as Keokuk is the distributing point for lumber for a large territory lying in Iowa, Missouri, and Illinois. Lumber is brought by river from the northern pineries and sawmills by steamboats in large rafts, either of logs or sawed lumber, each raft containing several million feet. The time required to make a run with a raft depends upon the stage of the water, as in higher water shorter channels can be run, and much time can be saved by running the Des Moines Rapids instead of the slow process of locking through the Des Moines Canal, and the cost of delivering a raft is lessened or increased according to the stage of the water. All persons interested in steamboating are benefited by the river bulletins, and all boats landing at this point, as a rule, consult the bulletins which are displayed at the regular landings, and in some cases when boats have not landed they have sent a yawl ashore for the purpose of consulting the bulletin. Farmers on the bottom lands lying in Illinois and Missouri south of the mouth of the Des Moines River are interested in times of threatened high water, and reports reach those sections at Warsaw, Ill., Alexandria, Lagrange, and Canton, Mo., in the regular river bulletin. Flood warnings have not been sent from this station, as the rise of the river is so gradual that timely warning may be had from the regular bulletin. There has been no flood of any consequence since May, 1888. In May, 1892, and again in 1893, the river rose above the nominal danger line (14 feet), overflowing a small tract of land in Missouri, and doing no material damage. Since May, 1893, the river has not reached the danger line at this point.

KNOXVILLE, TENN.

The interests most affected by river conditions at this place are those connected with navigation, and they are affected very little from the fact that this point is nearly at the head of navigation, the river being navigable only about 55 miles farther upstream. Owing to the high river banks along this portion of the stream, farming interests along the side of the stream are never in danger from floods, while property along the banks is equally free from liability to damage. In fact, it may be generally stated that in rare cases only is there any danger to be apprehended from high water in this section. River men state that stations up the stream would assist the navigation interests.

LITTLE ROCK, ARK.

As the low stage of water in the Arkansas River at this point has continued during a longer period in the last year than ever known before, the stages of water have assumed an importance hitherto unknown. When, during the late fall and winter months, the water is too low to ship by river the large quantities of cotton and cotton seed and merchandise of all kinds, freight of this class must be hauled long distances by wagon and shipped by railroad at greatly increased expense. During low stages of the river, when a slight rise is reported in the upper river, the boats can leave Little Rock and return with a full cargo with the rise, whereas if they were not informed of the rise at the earliest possible moment it would be too late to take advantage of it after it reached this city. This condition has existed many times during the past year, and the importance of the river intelligence has been demonstrated by the increasing demand for news of this nature. River warnings of floods are of incalculable value to all the inhabitants of the Arkansas Valley from Fort Smith to the mouth of the river, but chiefly so to those of the lower valley. From information received from a flood warning they can determine just what steps to take in strengthening and repairing levees, or if the anticipated flood is so great as to make it impossible to prevent overflows, they can move their household effects and stock to safe places. Floods are not common in the Arkansas Valley, and consequently levee protection is comparatively poor and not much attention is paid to the levees until the flood seems imminent. The section of country protected by levees is small, hence a very large section is subject to overflow, and included in this area are some of the finest cotton lands. No floods have occurred in the Arkansas River during the last two years, but from the benefits derived from the flood warnings of 1892 this branch of the work of the Bureau has since assumed an importance second to none. It is impracticable to make an estimate of the money value of the warnings issued, but they were the means of saving many lives and thousands of dollars' worth of property.

LOUISVILLE, KY.

Louisville is located upon a gently undulating plain which has an average elevation of about 70 feet above low-water mark. New Albany and Jeffersonville, on the opposite side of the river, are similarly situated at approximately the same elevation. Both above and below these cities high banks rise abruptly from the shore, except in occasional places where there are spots of limited area but slightly elevated above the river. As the highest water mark shown by the Weather Bureau record was 46.6 feet, on February 16, 1884, it will be seen that only in cases of floods of exceptional volume is property generally exposed to danger in this vicinity. That portion of the city which, by its location in the depression forming the valley of Bear Grass Creek, was formerly exposed to danger from even ordinary floods, has been protected by a high earthen wall which has diverted the stream from its original course. A depth of 30 feet will flood cellars fronting immediately upon the river and a portion of Portland, a small suburb west of the city, and a rise to 35 feet will endanger a considerable amount of property. Warnings of these stages have frequently proved of great value. On an average of once in three years the water rises to a stage that jeopardizes considerable property, and in such cases the warnings are of great value. The highest water during the last two years was 28.8 feet, February 22, 1893, but it resulted in no material damage. On account of the infrequency of flood stages of water and the comparatively small amount of property endangered by them, flood warnings are considered subordinate in importance to the daily reports of the fluctuations of the river, affecting as they do many and diversified interests.

The States contiguous to the Ohio and Mississippi rivers are in the main dependent for their fuel supplies upon the coal which comes from the Upper Ohio and its tributaries, and the annual consumption is many millions of bushels. Nearly all of that destined for points west and south of here has to pass Louisville, and it is of the highest importance to dealers and shippers, both here and elsewhere, to be informed as to the stage of the water in the river, particularly the depth of water in the canal, through which the coal fleets must pass. A rise or fall of even a few inches may be of great moment to this industry, and, while no data bearing upon the subject is accessible, information furnished by this office has been of unquestioned pecuniary value. This statement is true also in a lesser degree in regard to the shipping of other classes of freight and to general river traffic. The work of widening the Louisville and Portland Canal, which is in charge of the United States engineers, has been in progress for ten years or more, and can be conducted only when the water is low enough to expose a portion of the river bed. A sudden rise, even of a few feet, will endanger all the costly apparatus used in connection with the operations, and upon several occasions during recent years it has been saved through information furnished by the reports of this office. In the same manner the cement industry has been greatly benefited, since the rock used in its manufacture is obtained from the bed of the river, and the tools, tracks, engines, cars, and other apparatus are constantly exposed to danger from sudden rises.

It is only during severe winters that the Ohio is closed by ice at this point, but in the winters of 1892-93 and 1894-95 it was frozen for considerable periods. The breaking up of the ice is a serious menace to all floating property, and warnings received during the winters mentioned were of the highest value. The breaking up of the ice in January, 1893, caused the loss of $200,000 worth of coal, but it is a notable fact that owners who took precautionary steps suffered but little loss, and it is estimated that more than the above-mentioned amount was saved through warnings of the approaching break. Warned by the experience of 1893, river men generally heeded the information furnished to them during the past winter, and, as a result, the breaking up of the ice was accompanied by practically no loss. Warnings of high winds have not infrequently been attended by the most valuable results to river interests. The most notable cases of this kind were those of March 27, 1890, which, from a conservative estimate, resulted in the saving of property valued at $100,000 and 50 lives; and March 24, 1893, when $20,000 and probably many lives were saved.

While the benefit of the flood warnings, in the strict sense of the word, can not be so great here as in districts subject to periodical overflow, yet the river-report service is considered one of the most important and highly appreciated features of the work of the Weather Bureau in this section.

MEMPHIS, TENN.

All business interests in this community are affected by the condition of the rivers, and when flood or high water threatens, the interest is intensified over the entire area subject to overflow. It is estimated that a little more than three-fourths of the cotton-producing territory tributary to Memphis is subject to overflow during extreme high water, or is behind the levees of the Mississippi, Arkansas, and St. Francis rivers. The great length of the season required for the maturity of cotton renders this crop especially subject to damage from protracted high water, and when flood threatens it is of the utmost importance to know not only what portion of the lands will probably be submerged, but the probable length of time they will remain under water, in order that advantage may be taken upon the subsidence of the water to replant in cotton, if there is sufficient time, or in some other crop should the season be so far advanced as to render the maturity of cotton uncertain.

The Weather Bureau reports of the daily rainfall and river stages are the only authentic source of information accessible to the planter who has at stake probably his entire capital, and to whom a flood means ruin or privation. When a flood threatens, every scrap of information and every opinion as to the probable height the river will reach is read and discussed at every post-office and crossroad throughout the valley, and while the knowledge that a flood will occur might not enable the planter to save a pound of cotton on land subject to overflow, nevertheless it is knowledge of the greatest importance to him, as preparation can then be made to place property in a position where it will be subject to the least damage.

Flood warnings are absolutely indispensable to those directly interested in the protection of the levees. When the water reaches a danger point it is necessary to have the levees under the most careful surveillance, and to this end the interest of the people must be aroused to the possibility of danger. Nothing is so effectual for this purpose as the information furnished by this Bureau. Much credit is due Capt. A. A. Sharp, superintendent of the Yazoo and Mississippi Valley Railroad, for his efforts in furnishing information of impending floods to the people of the valley. This railroad follows the Mississippi River from Memphis to Vicksburg, and Captain Sharp has arranged with this office to obtain the stages at the principal points on the upper rivers at the earliest possible moment each morning. These stages, together with the river forecasts, are telegraphed to all stations on his line and promptly posted. This keeps the people thoroughly in touch with the latest information on the condition of the rivers, and is received at least thirty hours in advance of the daily papers. I am unable to point to any instance and say that the warning saved so many dollars—such examples are exceedingly rare; but when a planter makes a journey of 75 miles with no other purpose than to obtain the latest information as to the probable extent of the threatened flood, the value of such information to him may not be questioned. Two instances of this kind came under my personal notice during the high water of 1893.

The value of the daily river reports to those directly interested in river traffic is manifest, especially when the river is low and care must be exercised in loading in order to pass safely over shoals which may be in the channel. These points are closely watched by steamboatmen, and the daily reports of the Bureau form the basis of calculation as to the cargo a boat may safely carry. The value of such information is evident, though it is difficult to estimate in dollars and cents.

MINNEAPOLIS, MINN.

The principal interests affected by the river conditions in this locality are the lumber industry, the flour mills, and the city waterworks. When the river stage is low the season's cut of lumber can not be floated into the Mississippi, and some of the sawmills are obliged to shut down. The mills use all the water they can get for power, and when the water is low they are obliged to use their more expensive steam plants. The annual spring rise usually floods some of the cottages nearest the river bank in a district known as the "Bohemian Flats," which is located below the falls and contains a settlement of squatters. The loss is, however, insignificant. No warnings of floods or high water have been furnished to or issued from this office during the last two years.

MOBILE, ALA.

The Alabama River system is nearly a thousand miles in extent, embracing the Alabama, Warrior, and Tombigbee rivers. These rivers and their tributaries bring the products of the mines, cotton fields, and forests to manufacturing and shipping centers. This river system has been in operation about two years, and in importance is only equaled by the daily weather forecasts. The value of the commercial products reaching Mobile through the medium of the Alabama River system varies from $10,000,000 to $15,000,000 annually, and when it is remembered that there are times when navigation is seriously embarrassed, if not entirely suspended, the importance of the daily river reports, the only source of information concerning the rivers, can be readily seen. River transportation has a formidable competitor in the railroad system, traversing as it does a large section of the river territory. This fact calls for the closest study of the conditions of the rivers and the rainfall by steamboatmen, as it enables them to accept or reject cargoes.

Almost daily, persons interested in river navigation call for the water stages before the information is officially issued. If reports are favorable, steamers are laden and dispatched to points which, owing to low water, have not been visited for weeks. If reports are not favorable, freight is not received. Thus it will be seen that these reports are valuable, not only to the steamboat owner, but likewise to the planter, who receives the benefit of the lower rates of water transportation. Lumbermen, loggers, and shingle manufacturers show equal interest in the daily river bulletin, all of these interests desiring high water. The recent heavy rains over Alabama, Georgia, and Mississippi show the relation this office bears to this community, and what a factor it is to the business interests. For some months the mills of the city had almost ceased operations for want of supplies, owing to a deficiency in the spring rains. Large quantities of lumber had been cut, and arrangements had been perfected to float it down to this city with the first high water. The rains mentioned were sufficient to cause the streams to reach the danger line. Immediately on receiving official notice of the coming rise, thousands of loggers were sent to the swamp country contiguous to the rivers, and hundreds of rafts were brought to the rivers and floated to this city. Without the information furnished by the reports of this office, valuable time would have been lost and very few logs would have been secured, owing to the very short period the high stage continued. A foreknowledge of high water enables stockmen to drive their cattle to safe places. The reports are of incalculable benefit during the low stages of water which continue during the greater portion of the year, as the information they contain is a leading factor in the navigation of all rivers.

MONTGOMERY, ALA.

A majority of the business interests of this community are directly or indirectly affected by high water and floods in our rivers. This city is a commissary depot for all of the river basin of this section, covering thousands of square miles, and any influence brought to bear on the agricultural or stock-raising interests is felt at once. There are thousands of acres of fine bottom land on which corn and cotton is grown which is subject to overflow. It is impracticable to gather accurate statistics of the value of such interests, but from the most reliable information obtainable the value of such interests in this county alone which are affected by river conditions will aggregate $200,000. The manufacturing interest is not large, and would not exceed $50,000 annually. The shops of the Louisville and Nashville Railroad and the Western Railway of Alabama are located on ground which would be flooded by extremely high water. The value of machinery and other movable property at both shops is several hundred thousand dollars. The value of the reports to the mercantile interests is also very great, as at most of the river landings where freight is discharged the means of protecting the freight from high water after it is landed are very meager, and during periods of high water arrangements have to be made in advance for the prompt removal of goods to high ground. It is difficult to estimate the value of merchandise so affected, but it is fair to assume that it would aggregate $50,000 to $75,000 annually. The timber interests affected by river conditions are also considerable. In the swamp lands, where at times there is a large quantity of timber ready to be hauled to the mills, unexpected high water would float it away and cause serious loss. The estimated value of timber in this section so affected is $75,000 to $100,000 annually.

During the winter and spring most of the live stock is kept in the canebrakes of the river bottoms, on account of the better pasturage. As these are the seasons when we have our most sudden rises, our reports and warnings are of vital importance to the stock raisers, and this interest represents about $100,000 annually.

No floods, and but few ordinary high rises, have occurred in the last two years, and in the case of the rises full and ample warnings were issued. Several days' warning was given of the high waters of March 15 to 21, 1895, the warnings being telegraphed to nearly all river stations and mailed to all postmasters at river towns within mailing distance, and while the water was not high enough to do any serious damage, it is thought that the warnings saved considerable loss of stock and other property in the bottom lands. The forecasts and warnings issued at that time have certainly increased the public confidence in this branch of our work, which in this section is one of the most important of the Bureau.

As before stated, it is impracticable to obtain more than approximate estimates as to the value of the various interests in this section affected by river conditions and benefited by our warnings, but for the Alabama and Tombigbee systems of rivers it is thought the following is a conservative estimate of the annual value of the different interests:

Agriculture	$1,500,000
Stock raising	100,000
Manufactories of all kinds	500,000
Lumbering	200,000
River commerce (indirectly affected and benefited)	15,000,000
Total	17,300,000

The reports and warnings are also of great benefit to the officers in charge of the Government improvement of the rivers of this section, for which large and costly plants are maintained, and which our warnings have often been the means of protecting from damage by sudden high water. Railroad officials derive value from the reports during periods of high water, as they are enabled to protect their bridges and other property. The Capital City Waterworks of this city, which obtains water from an artesian supply, is also affected by river stages of 15 feet or more, and extra precautions to prevent damage are taken when warnings of stages above 15 feet are received.

NASHVILLE, TENN.

The principal interests affected by the condition of the river at this point are those connected with steamboating, lumber, manufactories, and merchants and dwellers in houses along the river banks and in the low districts. There are three large sawmills on the banks of the river, two of which are seriously inconvenienced by a stage of 38 to 40 feet, while the third can stand 45 feet without much damage to its property. These mills are in the habit of stacking lumber on the river banks, and it frequently happens that heavy rains at points above Nashville cause quick and decided rises here. These rises are shown through reports from the special river stations at Burnside, Ky., and Carthage, Tenn., in time to notify the owners of the lumber to remove it to places of safety. If it were not for the river service, the first intimation these owners would have would be the arrival of the crest of water which would carry off a part, if not all, of their lumber. During the rise in February, 1893, one mill alone had about $1,000 worth of lumber stacked on the banks a few feet above the water. On the 17th of that month it was seen by the reports of stations above that the danger line would probably be reached or passed during the ensuing few days, and bulletins were issued to that effect, and warnings were given to remove all movable property above that line. A large force of men was put to work, and every foot of lumber was removed to a safe place. and none was lost. By the morning of the 21st the water had risen one-half foot above the danger line. One firm stated that this warning saved them over $2,000. The owners of small tenement houses in the districts subject to overflow are also especially benefited by the warnings. The brick manufacturers are enabled by the warnings to bank their fires and stop their machinery, and in other ways to protect themselves and save considerable money. The danger line has been passed but one other time during the last two years—February 9 to 11, 1894. At that time the warnings were widely distributed by means of the bulletins and the telephone, and while no special instance is known, I am convinced that much money was saved by the warnings. The warnings are probably of greatest value to the steamboat interests. When the water is low and a rise occurs at the headwaters, they often send out a boat to load at some of the towns above and return with the rise. It is a very conservative estimate to say that the river service is worth to this city at least $25,000 a year.

NEW ORLEANS, LA.

Steamboat men, coal men, and plantation owners along the rivers are the persons most interested in the river reports, as a rule. The former gauge their time of departure according to the river reports of the Weather Bureau, particularly in the Red and Ouachita trade, and it is only through such reports and accompanying forecasts, when these rivers are at a low stage, that the trips can be made. The coal interests from Pittsburg down the Ohio and Mississippi rivers are particularly large in this city, and the river reports from the Ohio are in great demand, and serve to control the time of departure of coal fleets from the upper Ohio. During the past season, when the Ohio was at a low stage for weeks—so low as to make it hazardous to attempt starting the coal fleets from Pittsburg, and at a time when coal was becoming scarce in this city—timely information of an expected rise in the Ohio through anticipated rains resulted in a number of fleets starting down the Ohio and making their way to this port without grounding or being delayed by tying up. Incidents of this character are quite numerous, and prove the great value of the river reports and forecasts during low water. The rice planters along the Lower Mississippi are also greatly interested in river information disseminated by the Bureau. Flooding rice fields by means of pumping from the river is expensive, and when the reports indicate an anticipated rise sufficient to permit flooding by means of flumes a considerable outlay of money is saved to the planters, whereas if the reverse were the case the pumping method would be resorted to as a means of making the crop.

During the periods of high and flood waters the entire public is particularly interested in the reports and warnings. Boards of levee commissioners, engineers, plantation owners along the rivers, and in fact all riparian interests, keep a watchful eye on the Weather Bureau reports. During the spring of 1893—April and May—the levee system of the State was greatly strengthened on account of the timely warnings of the Bureau. Back, or protection, levees were thrown up, temporary levees were erected at points where it was feared the river would wash over its banks, and although breaks occurred and considerable damage was done, yet without the information furnished by the Bureau it is safe to assume that the damage would have been far greater and many lives would have been lost by the floods. Reports of families moving from the lowlands along the river front, and taking with them their stock, household furniture, etc., on the strength of the warnings issued by the Bureau were numerous, and although thousands of persons were rendered homeless during that overflow, yet the loss of life was comparatively small to what it would have been had no warnings been issued of the extreme stage expected in a given time.

It would be scarcely possible to give in a limited report full particulars of the far-reaching effects of the flood warnings; and even months in advance of the period of our usual high waters the riparian interests desire to know the Weather Bureau's opinion regarding anticipated floods, or the stage that can be expected. It is so far-reaching as to make jobbers in bagging lay in additional supplies to meet the demands of engineers, plantation owners, etc., for bags (to be filled with sand) to be used in the construction of temporary levees, and in closing crevasses, should any occur.

The detailed expression of opinion on the value of the warnings of the Bureau by the public, through the press, were forwarded to your office during the flood of 1893, and complete retained files are missing from other than city papers. The foregoing is, however, the general value of the reports as gleaned from a personal knowledge of the conditions that existed.

OMAHA, NEBR.

The business interests most affected by river conditions are corporations and companies having property located along the river, the aggregate value of which is millions of dollars, and a stage of water above the danger line would, without timely warning of its approach, cause immense loss. As the stage of the water at this point has not for years reached a point higher than 15.1 feet, which is 3 feet below the danger line, there has been no opportunity to demonstrate the value of the flood warnings in a marked manner. On April 12, 1893, and April 14, 1894, the water reached 15.1 feet, and the attention paid to the river reports and forecasts proved the faith given and the reliance placed upon the warnings and reports by those most concerned.

With reference to the river bulletin issued from this office, copies of which are furnished to all the interests affected by river conditions, a universal regret is expressed that the daily reports and changes of the river at Bismarck, Pierre, and Sioux City are not regularly published in the bulletin from April to June, inclusive, each year. This regret, while not publicly expressed, is also felt by the observer, who is seriously handicapped, at times, in making forecasts by a lack of information of the river conditions above his station.

PARKERSBURG, W. VA.

The timber and coal interests are particularly affected by the changing river conditions, and the greater of these is the timber interest. Timber and railroad ties are floated down the Little Kanawha, and the river reports indicate stages of water favorable for rafting. Knowledge of the river conditions renders it practicable for the lumber men to use the natural means of conveying their output at favorable times, and the warnings guard against surprises by floods and high water, thereby rendering comparatively safe a business which would otherwise be perilous and uncertain. Warnings of high water and floods are the means of saving merchandise piled upon the levees which would be destroyed if a flood came unannounced.

While warnings of floods are of the greatest value, warnings of even a slight rise in times of low water are of great value, as boats will often clear for up or down river points in anticipation of a small rise.

The warnings issued during the floods of February 11-17, 1893, and January 8-12, 1895, were very successful. In the former period great anxiety was felt on account of the high water. Bulletins giving the probable height beyond which the water would not rise did much to allay anxiety and evoked favorable comment from press and public. During the latter period the river conditions were constantly put before the people with equally good results.

PIERRE, S. DAK.

The highest point reached by the river in the last two years was 10 feet, April 3, 1893, the danger line being 13.1 feet. The only interest taken in the river is in times of threatened high water, as the business part of the town is nearly on a level with the river, and merchants move goods when the water approaches the danger line during the season when the ice breaks up. The river at this point is 1 mile wide and has a great many sand bars, and the benefits resulting from this station are confined to sending telegraphic reports to Sioux City in the event of rapid rises. If reports of high water at Bismarck, or rises of 3 feet in 24 hours at that place, could be received by telegraph, they would, in the case of a flood, be the means of saving thousands of dollars' worth of property in this vicinity.

PITTSBURG, PA.

At a stage of 3 feet the river is navigable for freight and passenger packets; at 3.5 feet for towboats and empty barges; at 7 feet for loaded barges; and at 9 feet for large tows of heavy coal boats. At 20 feet traffic on the Pittsburg and Western Railroad is suspended, and cellars in the lower portion of Allegheny City are flooded. Since 1872 a stage of 20 feet, or higher, has occurred 39 times. Twenty-five feet puts the water in the cellars of the business portion of Pittsburg. Damage has also occurred from 22, 23, and 24 foot stages. Disastrous floods have occurred with a 27-foot stage.

Persons interested in river navigation are affected by the river conditions at all times, and merchants and persons living in the lower parts of Pittsburg and Allegheny are affected by a stage of 20 feet, or higher. The river reports and flood warnings are of incalculable value to the river and coal operators. By means of our reports they are able to inform themselves twenty-four to thirty-six hours in advance of the probable stage of water, whether there will be sufficient for navigation, or enough to move the heavy coal boats or the lighter barges; giving them time to get their crews together and make necessary preparations. By a conservative estimate this saves to every coal firm in this vicinity shipping by river $5,000 per year.

As an instance of the value of the flood warnings the floods of the present year may be considered. On Sunday, January 6, at 8 a. m., the stage at Pittsburg was 2.7 feet, and rain was falling along both rivers. Special observations were called for and were received about 4 p. m. These reports showed a slight rise in the Allegheny and lower Monongahela, and a decided rise and breaking up of ice in the upper Monongahela. Warnings were immediately issued stating that the stage would be about 15 feet Monday morning. By this warning the river operators made every preparation possible to secure their fleets against damage by high water, and no losses occurred in the harbor. I am informed from reliable sources that $100,000 worth of property was saved by this warning. The only losses in this vicinity were to the McKeesport ferryboat and the Jenkins docks in the Youghiogheny River, which were carried away; and these losses could have been averted had proper precautions been taken. At 8 a. m. of the 7th the stage of water was 12.2 feet and at 9.30 a. m. 16.5 feet. At that hour warnings were issued and telegraphed to points below, published in the newspapers, and given to interested parties by bulletin and telephone, stating the river would reach 26 feet by Tuesday morning, the 8th. As 25 to 27 feet of water floods many of the cellars in the business parts of the two cities and 30 feet many of the principal streets, this office was visited by hundreds of persons who wished to know whether their property would be damaged, and a man was kept constantly at the telephone from 10 a. m. to midnight answering inquiries. Many experienced river men predicted that a 30-foot stage would be reached, and this gave rise to many rumors of disastrous floods. Had the Allegheny River put out the volume of water it generally does, their predictions would have been verified; but this office was confident that owing to the colder climate of the Upper Allegheny Valley, caused by its elevation, and the approaching cold wave, the Upper Allegheny River would not put out much water. All persons whose interests were likely to be affected by a stage of 26 feet were advised to remove their goods; and all persons whose interests were not affected by that stage were advised to the contrary. It is estimated that property to the value of $500,000 was saved by this warning. This rise came from the Monongahela, Cheat, Youghiogheny, and Kiskiminitas rivers. The rivers rose rapidly during the 7th and the morning of the 8th. At 11.30 p. m. of the 7th the stage at Pittsburg was 24.4 feet, and the maximum stage, 25.8 feet, occurred at 12.45 p. m of the 8th.

In January and February of this year extensive ice gorges formed in the Allegheny River above the mouth of the Kiskiminitas; for about 90 miles the river was nearly a solid mass of ice, in many places as high as 50 feet. These gorges were a constant menace to property, and caused great anxiety in this vicinity Through the courtesy of the Allegheny Valley Railroad this office was informed of the movements of the gorges, and daily reports were received from Kittanning. With this information, and that received from the Weather Bureau observers, daily reports of the condition of the river and the probability of a break up were issued. As considerable alarm was manifested in this vicinity a special report was issued stating that there was no prospect of an extensive and general break up, and that no immediate danger need be apprehended. From March 21 to 25 the ice broke up and passed out without causing any damage. It is believed that the reports of the Bureau were the means of saving a large amount of property, and the work of the Bureau received much favorable comment from the public. Warnings of floods of preceding years, notably those issued in connection with the floods of February, 1891, were also the means of saving an immense amount of property.

PORTLAND, OREG.

Oregon is affected by floods from two causes: First, the Willamette freshets, which occur in February, when they do occur; and second, the June rise in the Columbia River. The former is produced by snowfalls followed by heavy warm rain; the latter by the rapid melting of the snow in the mountains of British Columbia, Washington, Montana, Idaho, and northeastern Oregon.

These floods cover the wholesale and a part of the retail business districts of Portland, causing a cessation of business; float wooden sidewalks; injure asphaltum streets; damage docks and warehouses; injure the river boat service and transportation; flood the tracks of the Northern, Union, and Southern Pacific railroads; flood mills and factories, and inundate thousands of acres in the Columbia and Willamette valleys. The largest single item of damage results from a cessation of business.

The people rely entirely upon this office for information concerning the rise and fall of the rivers and floods. The newspapers, too, rely exclusively upon this office for this information. This reliance in our reports on the part of both people and press is a measure of the value of the reports. As to the money value of the warnings, that is a difficult question to answer Immediately after the flood of June, 1894, an estimate was obtained from 30 merchants of this city relative to the value of the reports, and this estimate placed the money value of property saved by the warnings at $240,000. From verbal reports, newspaper expressions, etc., it would appear that our information enabled the saving of fully $500,000 worth of property. We have labored under the disadvantage of not having gauges on the upper rivers, but this has been corrected within the last six months; and, secondiy, the telegraph lines are frequently washed out just when we want reports.

During the last two years there has been but one opportunity of forecasting a flood and that was in May and June, 1894. The success attending our reports is shown by the following extract from the Portland Oregonian of June 10, 1894: "The merchants and other interested persons have relied entirely upon the Weather Bureau for information concerning the flood. Since May 21, when the river showed 18.3 feet, to June 4, the Weather Bureau has forecasted the rise. On the 4th a special bulletin was issued stating that the river would continue to rise until midnight of the 6th, it would remain stationary on the 7th, and a fall would be observable on the 8th. The prediction was verified most accurately. The Weather Bureau has established an excellent reputation in this and adjoining States during the past few years, and all of its river information has been most thoroughly verified."

There has been no flood in the Willamette since 1890, but there have been frequent rapid rises in that river, during all of which all interested parties relied upon this office for information, and I am pleased to note that not in a single instance in the last two years has a merchant lost upon the information received from this office.

RALEIGH, N. C.

The interests affected by river conditions in North Carolina are chiefly agricultural. Low-water stages are of interest to boatmen in the larger rivers of the eastern section of the State. High-water stages are a matter of concern, first to the population along the lower river courses in localities where the banks are apt to be overflowed and crops injured or destroyed (the districts liable to overflow include narrow strips along the lower courses, averaging some 2,000 to 3,000 square miles in area, of which the greater portion lies in the low alluvial plains of the east), and in a lesser degree to farmers who pasture stock on some of the islands which appear during low water; some of these islands, notably those in the Roanoke at and below Weldon, furnish fine pasturage, but are completely submerged during high water. High-water stages also concern lumbermen and merchants in the neighborhood of the docks in some of the larger cities, particularly at Wilmington.

The establishment of the river system in North Carolina is so recent that the estimate of the value of successful warnings must be regarded as a mere approximation. If floods occur at the season when crops are ready to be gathered it is estimated that a successful warning of approaching floods would cause a saving of $25,000 to $50,000. After crops are gathered the warning would save from $10,000 to $15,000. There have been but few instances during the last two years when flood warnings were required. No warnings were issued during the high stages of August, 1893, and damage, which might in part have been avoided had warnings been issued, was caused to standing crops. The warnings of floods in October, 1893, when the river reached a stage of 42 feet at Fayetteville and 34.6 feet at Weldon, resulted in the saving of much corn and fodder. During 1894 the rivers continued low, except a local rise of the lower Cape Fear, for which no warnings were issued, and which caused some damage to crops. In 1895 very successful warnings were issued January 9 and March 20. The Cape Fear River reached the highest stage ever known at Fayetteville, 58 feet, completely verifying the warning issued of "an unusually high stage in the Cape Fear River." The Roanoke reached 41 feet at Weldon, and the warnings resulted in the saving of stock on the islands. Although in these cases crops were not endangered to any great extent, it is estimated that the warnings resulted in the saving of some $5,000 worth of property.

RED BLUFF, CAL.

There are no interests in this immediate vicinity affected by river stages. It is only when the northern boundary of Colusa County is reached that the danger from floods along the Sacramento River begins. The land at that point, and most of the land south of there, is flat and but little above the bed of the river. Millions of dollars have been expended for protection works on this land, but owing to the soil being of a sandy nature and being infested by gophers and ground squirrels which are constantly at work boring into the levees, breaches occur occasionally when the water is high, and the land is flooded. On such occasions the damage sustained is great, for not only is the crop destroyed, but the land is rendered unfit for cultivation for two years after. The value to those localities of the river forecasts and flood warnings can not be overestimated when it is considered that by twelve hours' warning there is time before the flood arrives to repair holes in levees and otherwise put them in good order.

The writer has been informed that the timely warnings sent out by the Weather Bureau last December and January, of expected rises in the river stages, were the means of saving tens of thousands and perhaps hundreds of thousands of dollars to land owners in Colusa County alone. On December 21, 1894, the river at Red Bluff took a sudden rise. The rise was telegraphed at once to the forecast official at San Francisco. That official wired back that a dangerous rise was expected, and to warn places affected by high-river stages. The observer sent out flood warnings to points on the river as far south as Grand Island, and wired Hon. John Boggs, at Princeton, to warn his people and take necessary precautions against impending danger from flood. The result of these warnings was that the levees were strengthened before the flood wave reached the threatened localities. The highest stage of the river at Red Bluff in the last fifteen years was reached January 22, when the gauge reading was 26 feet. This rise was forecasted by the forecast official at San Francisco January 21, and the flood warnings were sent on that date by the observer at Red Bluff, with the result that little damage was done, as people were on the alert and looked after their levees.

The danger from overflow to the affected districts along the Sacramento River is increasing each year, owing to elevating causes going on in the bed of the river, and the importance of the flood warnings increase accordingly. Not only is valuable property in danger, but human life also.

SACRAMENTO, CAL.

All classes are affected, more or less, by the river during the rainy season, and towns and localities leveed against high water receive great benefit from the warnings. The old danger line at this place is 25 feet, but the levees will now stand a stage of 30 to 33 feet. The warnings are not only appreciated by people who live along the rivers, but by land owners who live in San Francisco.

ST. LOUIS, MO.

The interests most affected by river conditions are, in the order of their importance, river navigation, railroads, cotton merchants, grain receivers and shippers, and the many classes of business along the immediate river front, which are in danger of damage by overflow during flood periods.

As there have been no exceptional floods during the last two years, it is difficult to obtain much reliable data concerning the value of flood warnings during that time. It is safe to say that property to the value of $2,000,000 which would be destroyed or damaged by flood is directly interested in the flood warnings. On May 1, 1893, one firm in this city moved to a place of safety 6,000 bales of cotton, valued at $210,000, on the advice of the local forecast official then here, on account of the approach of high water. Another firm moved 12,000 bales, valued at $500,000, upon the same advice, making a total of $710,000 for one interest alone. As the water did not reach an exceptionally high stage at that time, it has been impossible to obtain any more data. During the high water of 1892 cotton valued at $1,250,000 was moved to a place of safety on the advice of the local forecast official then here. Since May 1, 1893, there has been no occasion for flood warnings here.

ST. PAUL, MINN.

The particular interests affected are the stock yards and beef and pork houses in South St. Paul, and manufacturing establishments and store cellars on the flats of West St. Paul, all of which have been established since 1881, when the highest stage of water, 19.7 feet, was reached. Provisions were subsequently made to guard against damage from a like stage by levees and filling up the lowland, and when a stage of 13 to 14 feet is reached some inconvenience and slight damage is caused by seepage of water into cellars, etc. At stages of 11 to 14 feet numerous small houses on the flats are flooded. The maximum stage of water in the last two years has been 14.7 feet, and no serious damage resulted, and no special flood warnings have been received during that period.

SAN FRANCISCO, CAL.

The interests affected by flood warnings in California are located principally in the Sacramento and lower portion of the San Joaquin valleys, which section is a vast level plain with but very slight difference in elevation over a vast region, amounting altogether to more than 4,000 square miles of territory. This plain is surrounded by steep mountain slopes on every side and the débris from the mountain streams has been deposited along the rivers in the valley, thus raising the surface of the valleys near the river considerably above that of the territory on either side in such a manner that when heavy rain occurs, which causes the rivers to overflow their banks, the water pours into these basins, thus overflowing a territory of about 1,500 square miles. This territory is composed of very rich alluvial land and a large portion of it has been in a measure reclaimed by building levees, and such portions are used for agricultural purposes. A large portion of this partly reclaimed land thus produces very large crops, except in seasons of unusually high water, when the levees are insufficient to protect it from the overflow.

The floods in this valley usually occur in winter or early in the spring, when heavy snow lies upon the mountains, and heavy rain occurs with warm weather and causes a rapid melting of the snow, which, together with the rainfall, greatly increases the discharge of the tributary streams. The rise in the rivers in such instances is very rapid, amounting sometimes to as much as 4 or 5 feet per hour at Red Bluff. Thus far the only information this service has received for the purpose of giving warning of floods in this valley has been from stations near the foothills just where the tributaries spread out from the canyons in the mountains into the plain of the valley, and the time limit is totally insufficient to give proper warning for points affected by the overflow, and on this account the work of this service in the past has been of slight value and has been principally confined to giving ranchers warning of the overflow, thus permitting them to remove stock and property to places of safety. The warnings sent from information received from Red Bluff last winter showed that warnings for even a slight period would be of value in permitting repairs to be made in the levees. Warnings for twenty-four and thirty-six hours in advance are possible for points from Sacramento southward. These warnings have been of marked value during the past winter, especially in one instance when high north winds were anticipated which cause rapid washing of the levees on the south side of the overflow district, which then embraced a territory 30 miles in extent. The levees thus exposed were protected by sand bags, and many places along the lower Sacramento River were probably saved from overflow thereby.

Arrangements have just been completed by which in another season reports will be obtained from points well up on the mountain slopes which will give information of rains and temperature and the rate at which snow is melting, and it is hoped that when this plan is perfected it will be possible to decidedly improve the system in various ways and give warnings at least twelve hours earlier.

SAVANNAH, GA.

Information pertaining to the Savannah River is of great importance and benefit to farmers and rice planters located along the river. During high stages they are greatly interested in the stage at Augusta, particularly the maximum stage attained at that point. It requires seven days or more for the crest of a freshet to reach Savannah after the maximum has been reached at Augusta, and farmers and rice planters have ample time to make such arrangements as they may deem necessary for the protection of their crops. The time required for the crest to reach this point, and the danger attending it, depends upon the weather conditions for several day preceding a freshet. Should the swamps be low the freshet is slow in coming down, and the filling of the swamps diminishes the height of the freshet crest. If a freshet is preceded by a protracted wet spell reverse conditions result. It is in knowing what the weather conditions have been and what they are likely to be that enables planters to take such precautions as will best secure the safety of their crops and other property. It is not with freshets alone that planters have to contend, but also with the severe local storms that occasionally visit this section. Warnings of the storms of August 27 and 28, 1893, and of September 26 and October 9, 1894, were the means of saving many thousands of dollars to rice planters along the river adjacent to Savannah, as those who had crops in the field flooded the fields and prevented serious loss by beating winds, and rice that had been cut and stacked was secured as well as possible and suffered no serious damage.

SIOUX CITY, IOWA.

The interests most affected by the river conditions are those of the Iowa and Nebraska Pontoon Bridge Company, which has $25,000 to $30,000 worth of property in the bed of the Missouri River. This property can not be held against the force of floods, running ice, or even a high stage of water, and unless the company had notice of the approach of high water and secured their property along or on the banks, it would be carried down the stream and lost. The Interstate Bridge Company, formerly the Pacific Short Line Bridge Company, also has a million-dollar bridge partly completed and a large amount of property on the banks adjacent to the works. This property would be in great danger should the stage of water approach the danger line—18.7 feet.

About one-fourth of the population of the city, the principal manufactories, the large packing houses, car shops, roundhouses, and railroad switching yards are located on the flats and are exposed to danger of floods in both the Missouri and Floyd rivers. The value of these interests is very great, and it is estimated that $75,000 to $100,000 worth of property could be saved in that section on a twelve to twenty-four hour warning of a great flood.

A marked instance of the success of the warnings occurred March 10, 1893, when the construction company at work on the Pacific Short Line bridge had $10,000 worth of material and machinery on its tramway to the center of the river, and were enabled by means of telegraphic reports from Bismarck, Pierre, and Yankton to remove half of this property on the approach of high water. The remainder, with half of the tramway, valued at $5,000, was carried away. In this instance property to the value of $5,000 was saved at a cost of not more than $5 for telegrams.

VICKSBURG, MISS.

The agricultural interests are especially affected by the river conditions in this locality. An estimate of the value of flood warnings would be impossible, and the accuracy of the warnings is always assured in a great measure as the floods can be predicted some time in advance of their approach to the Lower Mississippi.

The flood warnings allow the planters in the bottom lands to move their stock and other property to high ground. On the other hand, when no rise in the river is indicated the planters raise a large crop on the bottom lands.

The benefits of the river reports are universal, and it would be impossible to estimate their money value for any one year. The reports are eagerly sought for by all persons whose interests are connected with the river. The daily newspapers keep the river reports and forecasts prominently before the public, and the large and constantly increasing demand for the river bulletins attest to the great interest therein.

YANKTON, S. DAK.

No flood warnings have been received during the last two years, and no estimate of their value can, therefore, be given. The principal interests affected by river conditions are the agricultural, as the flooding of farm lands would destroy crops and property and endanger life. Public safety is affected by the possible carrying away of railroad bridges and embankments. For these reasons the flood warnings and river reports would be of great value and would be much appreciated in this vicinity.

RIVER DISTRICTS AND STATIONS.

The river and flood service was reorganized on July 3, 1893, and the duty of warning communities resident along the great rivers placed in the hands of the local forecast officials at the principal river centers. Each forecaster in charge of a river center has a definite section of the river system of his district to watch and forecast for. The information is thus more rapidly disseminated, and, being so directed as to reach those to whom it is naturally of most importance, is of more value than under any previous arrangement. Our river centers are furnished with all the data available relative to the condition of the rivers and the history of previous floods. The local forecasters, therefore, are equipped as completely as possible for the work before them, and with such advantages and their own experience and ability it is thought that no disastrous rise of the waters will occur without adequate warning of the same having been given to all concerned.

Territory is assigned as follows:

The observer at New Orleans is in charge of forecasts for the Mississippi River from below Vicksburg, the Red and the Ouachita rivers; the observer at Vicksburg takes charge of the river from Memphis to Vicksburg; the observer at Memphis, the St. Francis River and the Mississippi at Memphis; the observer at Cairo takes that section of the Ohio from Evansville to Cairo and the Mississippi from below St. Louis to Memphis; the observer at St. Louis takes charge of the Mississippi from Davenport to St. Louis and the Missouri east of Kansas City; the observer at Omaha takes the Missouri from Kansas City northward; the observer at Cincinnati takes the Ohio and its tributaries from Evansville to Marietta, and the observer at Pittsburg the Ohio and its tributaries above Marietta, while the Cumberland is watched from Nashville and the Tennessee from Chattanooga; the rivers in Alabama are watched from Montgomery; in North Carolina, from Raleigh; in South Carolina, from Charleston; the Arkansas, from Little Rock; the Mississippi above Davenport, from Davenport; the Susquehanna, from Harrisburg; the James, from Richmond; the Potomac, from Washington; the Savannah, from Augusta; the Snake, Willamette, and Columbia rivers, from Portland, Oreg., and the Sacramento and San Joaquin, from San Francisco.

The stations may be grouped as follows:

Stations making forecasts daily of the river conditions: Cairo, Chattanooga, Cincinnati, Davenport, Memphis, Nashville, New Orleans, Pittsburg, St. Louis, and Vicksburg.

When floods are imminent, in addition to the above stations, the observers at Augusta, Harrisburg, Albany, Raleigh, Little Rock, Mobile, Montgomery, Atlanta, Washington, San Francisco, Omaha, Portland, Richmond, and Charleston make forecasts of the river conditions.

List of special river stations.

Station.	River.	Reports to—
Albany, Ga	Flint	Atlanta.
Albany, Oreg	Willamette	Portland, Oreg.
Alexandria, La	Red	New Orleans.
Arkadelphia, Ark	Washita	Do.
Arkansas City, Ark	Mississippi	Vicksburg.
Arlington, Mo	Gasconade	St. Louis.
Arthur City, Tex	Red River	New Orleans.
Bagnell, Mo	Osage	St. Louis.
Bainbridge, Ga	Flint	Atlanta.
Bayou Sara, La	Mississippi	New Orleans.
Beardstown, Ill	Illinois	St. Louis.
Beaver Dam, Pa	Ohio	Pittsburg.
Bismarck, N. Dak	Missouri	Bismarck.
Bluff City, Tenn	Holston	Chattanooga.
Boonville, Mo	Missouri	St. Louis.
Brookville, Pa	Red Bank	Pittsburg.
Buchanan, Va	James	Lynchburg.
Burnside, Ky	Cumberland	Nashville.
Camden, Ark	Ouachita	New Orleans.
Camden, S. C	Wateree	Charleston.
Canton, Ga	Etowah	Atlanta.
Carthage, Tenn	Cumberland	Nashville.
Catlettsburg, Ky	Ohio	Cincinnati.
Charleston, Tenn	Hiwassee	Chattanooga.
Charleston, W. Va	Great Kanawha	Cincinnati.
Chester, Ill	Mississippi	Cairo.
Cheraw, S. C	Pedee	Charleston.
Circleville, Ohio	Scioto	Cincinnati.
Claiborne Landing, Ala	Alabama	Montgomery.
Clarksville, Va	Roanoke	Raleigh.
Clarion, Pa	Clarion	Pittsburg.
Clinton, Tenn	Clinch	Chattanooga.
Columbia, Tenn	Duck	Cairo.
Columbus, Ga	Chattahoochee	Atlanta.
Columbus, Miss	Tombigbee	Montgomery.
Confluence, Pa	Youghiogheny	Pittsburg.
Conway, S. C	Waccamaw	Charleston.
Cordova, Ala	Big Warrior	Montgomery.
Coushatta, La	Red	New Orleans.
Danville, Va	Dan	Raleigh.
Dardanelle, Ark	Arkansas	Little Rock.
Davis Island Dam, Pa	Ohio	Pittsburg.
Dayton, Ohio	Miami	Cincinnati.
Delhi, La	Bayou Macon	New Orleans.
Demopolis, Ala	Tombigbee	Montgomery.
Donaldsonville, La	Mississippi	New Orleans.
Dublin, Ga	Oconee	Atlanta.
Eddyville, Ky	Cumberland	Cairo.
Edisto, S. C	Edisto	Charleston.
Effingham, S. C	Lynche's River	Do.
Elwood Junction, Pa	Beaver	Pittsburg.
Eufaula, Ala	Chattahoochee	Atlanta.
Eugene City, Oreg	Willamette	Portland, Oreg.
Fair Bluff, N. C	Lumber	Charleston.
Fairmont, W. Va	Monongahela	Pittsburg.
Falmouth, Ky	Licking	Cincinnati.
Fayetteville, N. C	Cape Fear	Raleigh.
Florence, Ala	Tennessee	Cairo.
Freeport, Pa	Allegheny	Pittsburg.
Fulton, Ark	Red	New Orleans.
Gadsden, Ala	Coosa	Montgomery.
Grafton, Ill	Mississippi	St. Louis.
Greensboro, Pa	Monongahela	Pittsburg.
Greenville, Miss	Mississippi	Vicksburg.
Harpers Ferry	Potomac	Washington.

List of special river stations—Continued.

Station.	River.	Reports to—
Helena, Ark	Mississippi	Vicksburg.
Hermann, Mo	Missouri	St. Louis.
Hinton, W. Va	New	Cincinnati.
Johnsonville, Tenn	Tennessee	Cairo.
Johnstown, Pa	Stony Creek	Pittsburg.
Kingston, Tenn	Clinch	Chattanooga.
Kingstree, S. C	Black	Charleston.
Kleinston, Miss	Mississippi	Vicksburg.
Lafayette, Ind	Wabash	Cairo.
Leclaire, Iowa	Mississippi	Davenport.
Lockhaven, Pa	Susquehanna	Harrisburg.
Lock No. 4, Pa	Monongahela	Pittsburg.
Loudon, Tenn	Holston	Chattanooga.
Louisa, Ky	Big Sandy	Cincinnati.
Louisiana, Mo	Mississippi	St. Louis.
Lewiston, Idaho	Clearwater	Portland, Oreg.
Little Dallas[1]		
Macon, Ga	Ocmulgee	Atlanta.
Mahoning, Pa	Allegheny	Pittsburg.
Marietta, Ohio	Ohio	Cincinnati.
Melville, La	Atchafalaya	New Orleans.
Monroe, La	Ouachita	Do.
Morgantown, W. Va	Monongahela	Pittsburg.
Mount Carmel, Ill	Wabash	Cairo.
Mount Vernon, Ind	Ohio	Do.
Muscatine, Iowa	Mississippi	Davenport.
Natchez, Miss	do	New Orleans.
Newport, Ark	White	Vicksburg
Northport, Wash	Columbia	Portland, Oreg.
North McGregor, Iowa	Mississippi	Davenport.
Oil City, Pa	Allegheny	Pittsburg.
Paducah, Ky	Ohio	Cairo.
Parker, Pa	Allegheny	Pittsburg.
Peoria, Ill	Illinois	St. Louis.
Philippi, W. Va	Tygarts Valley Creek	Pittsburg.
Plattsmouth, Nebr	Missouri	Omaha.
Point Pleasant, W. Va	Ohio	Cincinnati.
Portsmouth, Ohio	do	Do.
Radford, Va	New	Do.
Reeds Landing, Minn	Mississippi	Davenport.
Red Wing, Minn	do	Do.
Resaca, Ga	Oostanaula	Atlanta.
Reynolds, Ga	Flint	Do.
Richmond, Va	James	Lynchburg.
Rockwood, Tenn	Tennessee	Chattanooga.
Rome, Ga	Coosa	Atlanta.
Rowlesburg, W. Va	Cheat	Pittsburg.
St. Joseph, Mo	Missouri	Omaha.
St. Paul, Minn	Mississippi	St. Paul.
St. Stephens, S. C	Santee	Charleston.
Salem, Oreg	Willamette	Portland, Oreg.
Saltsburg, Pa	Kiskiminitas	Pittsburg.
Selinsgrove, Pa	Susquehanna	Harrisburg.
Selma, Ala	Alabama	Montgomery.
Speers Ferry, Va	Clinch	Chattanooga.
Spokane, Wash	Spokane	Portland, Oreg.
Stoyestown, Pa	Conemaugh	Pittsburg.
Strawberry Plains, Tenn	Holston	Chattanooga.
Sturdevant, Ala	Tallapoosa	Montgomery.
Tallassee Falls, Ala	do	Do.
Terre Haute, Ind	Wabash	Cairo.
The Dalles, Oreg	Columbia	Portland, Oreg.
Towanda, Pa	Susquehanna	Harrisburg.

[1] See Northport, Wash.

List of special river stations—Continued.

Station.	River.	Reports to—
Tuscaloosa, Ala	Black Warrior	Montgomery.
Umatilla, Oreg	Columbia	Portland, Oreg.
Warren, Pa	Allegheny	Pittsburg.
Warsaw, Ill	Mississippi	St. Louis.
Weiser, Idaho	Snake	Portland, Oreg.
Weldon, N. C	Roanoke	Raleigh.
Wenatchee, Wash	Columbia	Portland, Oreg.
West Newton, Pa	Youghiogheny	Pittsburg.
Weston, W. Va	West Fork Monongahela.	Do.
Wetumpka, Ala	Coosa	Montgomery.
Wheeling, W. Va	Ohio	Pittsburg.
Whitesburg, Ga	Chattahoochee	Atlanta.
Wilkesbarre, Pa	Susquehanna	Harrisburg.
Wilsonville, Ala	Coosa	Montgomery.
Wittsburg, Ark	St. Francis	Memphis.
Yazoo City, Miss	Yazoo	Vicksburg.
Zanesville, Ohio	Muskingum	Cincinnati.

THE SYSTEM OF FLOOD WARNINGS.

There are now (January 1, 1896) in active operation 135 special river stations, 44 rainfall stations, and 38 regular river stations. The special work of the Weather Bureau in connection with the rivers of the country is to save life and property by giving timely warning of floods.

As yet the rules for flood forecasting are largely empirical. The observer in charge of any river center is, or ought to be, familiar with the main river and the tributaries, the area of the catchment basin and its topography, the frequency and the intensity of the rainfall, especially the intensity, the average time of passage of the flood crest between one station and another, and the history of past rises. Knowledge of low-water conditions, especially where bars and shoals exist, is perhaps of equally great importance as the knowledge of high water. Constant representations are made by steamboat and navigation interests that low-water conditions continue longer and affect navigation more. The observer is often able, with the means already referred to, to give the desired information; but his chief and foremost duty, in view of the fact that river improvements and measurements are otherwise provided for, is the dissemination of warnings when floods threaten.

RECORDS OF RIVER STAGES.

Records of river stages have been published as follows:

"Regular gauge histories," including readings on the Missouri River gauges from 1872 to 1886, both inclusive. Issued by the Missouri River Commission.

"Stages of the Mississippi River from Cairo to Carrollton, preliminary to stages of the Mississippi and its tributaries," including readings from 1871 to 1886, both inclusive. Issued by the Mississippi River Commission.

"Stages of the Mississippi River above Cairo and of the tributaries of the Mississippi River, except the Missouri River," including readings from 1871 to 1886, both inclusive. Issued by the Mississippi River Commission, 1889.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1887 and 1888." Compiled at the secretary's office, Mississippi River Commission, 1889.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri, for 1889." Compiled at the secretary's office, Mississippi River Commission, 1890.

"Missouri River Commission. Stages of the Missouri River from St. Charles, Mo., to Sioux City, Iowa." Compiled from miscellaneous and regular gauge records, 1886 to 1889, both inclusive. Mississippi River Commission print, 1890.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1891." Mississippi River Commission, 1892.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1892." Mississippi River Commission, 1893.

"Stages of the Mississippi River and of its principal tributaries, except the Missouri River, for 1893." Mississippi River Commission, 1894.

"Stages of the Ohio River and of its principal tributaries, 1858 to 1889, inclusive." Part I. Washington City, Signal Office, 1890.

"Stages of the Mississippi River and of its principal tributaries, except the Ohio River, 1860 to 1889, both inclusive." Part II. Washington City, Weather Bureau Office, 1891.

"Stages of water at miscellaneous river stations in California, Oregon, North Carolina, etc., 1875 to 1889, both inclusive." Part III. Washington City, Weather Bureau Office, 1891.

"Daily river stages at river-gauge stations on the principal rivers of the United States for the years 1890–1892." Part IV. Weather Bureau, 1893.

Report of the Chief Signal Officer, 1891, pages 67 to 260.

Report of the Chief of the Weather Bureau, 1891–92, pages 483 to 504.

From the data thus collected, covering now many years at some stations and shorter periods at others, the following general relations have been deduced:

The time it takes high water to pass from Pittsburg to Wheeling is one day; from Pittsburg to Parkersburg, two days; from Parkersburg to Cincinnati, three days; from Cincinnati to Cairo, six days; from Cairo to Vicksburg, seven days, and from Vicksburg to New Orleans, four days. From Pittsburg, therefore, to the Gulf requires twenty-two days. Since the time of travel is so great, it naturally follows that many interfering conditions arise tending to accelerate or retard the crest of the flood wave. No simple time rules are, therefore, possible.

The volume of water passing any given station in a given time is known only for a few places, and varies, of course, with high and low water. Nor can simple rules be based upon the rainfall, as the distribution over the drainage area is not always determinable.

Omitting for the present the rainfall relations, we find the following general relations concerning the movement of the water:

TABLES OF DISTANCES, RIVER TRIBUTARIES, AND RATE OF FLOOD MOVEMENT.

Beginning with the head of navigation on the Mississippi, St. Paul, Minn., we have the following:

	Distance by river channel from—		Number of days it takes high water to pass between stations.	Number of days to pass from station to Cairo.
	Gulf.	Cairo.		
Mississippi River:	*Miles.*	*Miles.*		
(1) St. Paul	2,057	917	....	9
(2) Red Wing	1,998	858	½	8½
(3) Reeds Landing	1,966	826	½	8
(4) La Crosse	1,867	727	½	7½
(5) North McGregor	1,819	679	½	7
(6) Dubuque	1,759	619	½	6½
(7) Leclaire	1,669	529	1½	5
(8) Davenport	1,653	513	¼	5
(9) Muscatine	1,622	482	½	5
(10) Keokuk	1,523	383	1	4
(11) Warsaw	1,518	378	1/12	4
(12) Quincy	1,482	342	½	3½
(13) Hannibal	1,462	322	¼	3¼
(14) Louisiana, Mo	1,433	293	¼	3
(15) St. Louis	1,321	181	1	2
(16) Cape Girardeau	1,183	43	1½	½
(17) Cairo (on the Ohio, 1 mile from mouth)	1,140	....	½	[1]13
(18) Memphis	910	230	2	[1]11
(19) Helena	834	306	1	[1]10
(20) Arkansas City	702	438	1	[1]9
(21) Greenville	662	478	1	[1]8
(22) Vicksburg	541	599	2	[1]6
(23) Kleinston	536	604	1/12	[1]6
(24) Bayou Sara	340	800	2	[1]4
(25) New Orleans	108	1,032	2	[1]2

[1] Number of days from station to mouth of river.

Yazoo.—Yazoo City, Miss., 65 miles to mouth of river; time of movement of water from station to mouth of river, two-thirds of a day.

St. Francis.—Wittsburg, Ark., 180 miles, and two and one-fourth days.

Illinois.—Beardstown, Ill., 76 miles from station to mouth of river; time, one day. Peoria, Ill., 141 miles; time, two days.

Des Moines.—Des Moines, Iowa, 175 miles; time, two days.

White.—Newport, Ark., 175 miles to Arkansas City (877 miles to Gulf); time, two days.

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	Distance by river channel from—		Movement to Cairo.	Movement between stations.
	Gulf.	Cairo.		
Ohio River:	*Miles.*	*Miles.*	*Days.*	*Days.*
Pittsburg	2,105.5	965.5	11	....
Davis Island Dam	2,100	960	10⅞	⅛
Wheeling, W. Va	2,015	875	10	⅞
Marietta	1,935	795	9⅛	⅞
Parkersburg	1,925	785	9	⅛
Point Pleasant	1,843	703	8⅛	⅞
Catlettsburg	1,791	651	7⅝	½
Portsmouth	1,752	612	7¼	⅜
Cincinnati	1,639	499	5⅝	1⅝
Louisville	1,507	367	4⅛	1½
Evansville	1,324	184	2	2⅛
Mount Vernon	1,288	148	1⅝	⅜
Paducah	1,187	47	½	1⅛
Cairo	1,141	1	....	½

	Distance from—			Movement to—	
	Gulf.	Cairo.	The Ohio.	The Ohio.	Cairo.
Wabash:	*Miles.*	*Miles.*	*Miles.*	*Days.*	*Days.*
Lafayette	1,466	326	198	2¼	4½
Mount Carmel	1,318	178	50	¾	2
Terre Haute	1,408	268	140	1½	3½
Miami:					
Dayton, Ohio	1,695	555	69	¾	6¾
Licking:					
Falmouth, Ky	1,669	529	30	⅓	6¼
Scioto:					
Circleville, Ohio	1,817	677	65	¾	8
Big Sandy:					
Louisa, Ky	1,816	676	26	⅓	7¾
Great Kanawha:					
Charleston, W. Va	1,904	764	61	¾	8⅞
Hinton, W. Va	1,999	859	156	1¾	10
Radford, Va	2,049	909	206	2¼	11
Muskingum:					
Zanesville, Ohio	2,000	860	65	¾	10
Beaver:					
Elwood Junction	2,092	952	12	1/10	[illegible]
Allegheny:					
Warren, Pa	2,272	1,132	167	2	13
Oil City, Pa	2,218	1,078	113	1½	12½
Parker, Pa	2,178	1,038	73	¾	12
Mahoning, Pa	2,155	1,015	50	½	11¾
Freeport, Pa	2,131	991	26	¼	11½
Pittsburg, Pa	2,105	965	....	....	11

The Allegheny and Monongahela form the Ohio at Pittsburg. The Kiskiminetas, Red Bank, and Clarion are tributaries of the Allegheny.

	Distance from—				Movement to—	
	Gulf.	Cairo.	Pittsburg.	Allegheny.	The Ohio.	Cairo.
Kiskiminetas:	*Miles.*	*Miles.*	*Miles.*	*Miles.*	*Days.*	*Days.*
Saltsburg, Pa	2,153	1,013	48	22	¾	11¾
Red Bank:						
Brookville, Pa	2,196	1,056	91	30	1	12
Clarion:						
Clarion, Pa	2,202	1,062	97	19	1	12
Stony Creek:						
Johnstown, Pa	2,220	1,031	90	64	1	12½
Stoyestown, Pa.[1]	....	....	....	....	....	....

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[1] About 15 miles south of Johnstown, on the Conemaugh.

Tygarts Valley River, Cheat, and Youghiogheny empty into the Monongahela.

	Distance from—			Movement to—	
	Gulf.	Cairo.	The Ohio.	The Ohio.	Cairo.
Monongahela:	*Miles.*	*Miles.*	*Miles.*	*Days.*	*Days.*
Weston, W. Va	2,266	1,126	161	2	2
Fairmont, W. Va	2,224	1,085	119	1½	12½
Morgantown, W. Va	2,200	1,060	95	1 1/12	12
Greensboro, Pa	2,186	1,046	81	1	12
Lock No. 4, Pa	2,145	1,005	40	½	11½

	Distance from—			Movement to—	
	Gulf.	The Ohio.	The Monongahela.	The Ohio.	Cairo.
Tygarts Valley River:	*Miles.*	*Miles.*	*Miles.*	*Days.*	*Days.*
Philippi, W. Va	2,260	155	36	1¾	12¾
Cheat:					
Rowlesburg, W. Va	2,226	121	40	1½	12½
Youghiogheny:					
West Newton, Pa	2,136	31	10	¼	11¼
Confluence, Pa	2,180	75	65	¾	11¾

	Distance from—		Movement to Cairo.	Distance by river—		Movement from station to mouth of river.
	Gulf.	Cairo.		From Cairo.	To mouth of river.	
Tennessee:	*Miles.*	*Miles.*	*Days*	*Miles.*	*Miles.*	*Days.*
Knoxville, Tenn	1,781	640	7	680	640	7
Loudon, Tenn	1,723	582	6¼	624	582	6¼
Rockwood, Tenn	1,685	544	5¾	584	544	5¾
Chattanooga, Tenn	1,596	455	5	495	455	5
Florence, Ala	1,361	220	3	266	220	3
Johnsonville, Tenn	1,235	94	1¼	140	94	1¼

The Duck, Hiwassee, Clinch, and Holston empty into the Tennessee.

	Distance to mouth of river.	Time to mouth of river.
Duck:	*Miles.*	*Days.*
Columbia, Tenn	70	1
Hiwassee:		
Charleston, Tenn	18	¼
Clinch:		
Kingston, Tenn	5	1/12
Clinton, Tenn	51	¾
Speers Ferry, Va	....	....
Holston:		
Strawberry Plains, Tenn	20	¼
Bluff City (South Fork), Tenn	....	....

The Cumberland empties into the Ohio.

	Distance from—		Time to mouth of river.
	Cairo.	Mouth of river.	
Cumberland:	*Miles.*	*Miles.*	*Days.*
Burnside, Ky	474	404	5
Carthage, Tenn	297	227	2¾
Nashville, Tenn	215	145	1¾
Eddyville, Ky	....	30	⅜

The Arkansas empties into the Mississippi.

	Distance from—		Time to mouth of river.
	Gulf.	Mouth of river.	
Arkansas:	*Miles.*	*Miles.*	*Days.*
Fort Smith, Ark	1,095	351	4
Dardanelle, Ark	1,000	256	2¾
Little Rock, Ark	920	176	2

	Distance by river channel to mouth of river.	Time to mouth of river.		Distance by river channel to mouth of river.	Time to mouth of river.
The Missouri:	*Miles.*	*Days.*	The Shenandoah:	*Miles.*	*Days.*
Fort Buford, Mont	1,663	....	Riverton, Va	45	½
Bismarck, N. Dak	1,327	....	The Susquehanna:		
Pierre, S. Dak	1,132	....	Towanda, Pa	256	3
Yankton, S. Dak	....	....	Wilkesbarre, Pa	181	2½
Sioux City, Iowa	802	8	Selinsgrove, Pa	117	1½
Omaha, Nebr	667	6¾	Harrisburg, Pa	72	1
Plattsmouth, Nebr	639	6½	West Branch of Susquehanna:		
St. Joseph, Mo	479	5	Lock Haven, Pa	65	1
Kansas City, Mo	386	4	The Atchafalaya:		
Boonville, Mo	197	2½	Melville, La	96	1½
Hermann, Mo	101	1¼	The Red:		
The Gasconade:			Arthur City, Tex	799	10
Arlington, Mo	65	1	Fulton, Ark	676	8
The Osage:			Shreveport, La	449	5¼
Bagnell, Mo	65	1	Coushatta, La	299	3¾
The James:			Alexandria, La	139	1¾
Lynchburg, Va	251	3	The Ouachita:		
Richmond, Va	104	1¼	Camden, Ark	485	6
Buchanan, Va	99	1	Monroe, La	271	3¼
Savannah:			Bayou Bœuf:		
Augusta, Ga	....	....	Girard, La	245	3
Potomac:			Bayou Macon:		
Harpers Ferry, W. Va	164	2	Delhi, La	275	3¼
Washington, D. C	104	½			

The Etowah and Oostanaula form the Coosa; the Coosa and Tallapoosa form the Alabama; the Locust and Mulberry forks form the Black Warrior, which empties into the Tombigbee; the Alabama and the Tombigbee form the Mobile.

	Distance by water to mouth of river.	Time to mouth of river.		Distance by water to mouth of river.	Time to mouth of river.
The Alabama:	*Miles.*	*Days.*	The Oostenaula:	*Miles.*	*Days.*
Montgomery, Ala	215	2½	Resaca, Ga	30	½
Selma, Ala	117	1½	The Etowah:		
Claiborne, Ala	45	½	Canton, Ga	55	½
The Coosa:			The Tombigbee:		
Wilsonville, Ala	75	1	Columbus, Miss	295	3½
Gadsden, Ala	135	1½	Demopolis, Miss	135	1½
Rome, Ga	216	2½	The Black Warrior:		
The Tallapoosa:			Tuscaloosa, Ala	131	1½
Sturdevant, Ala	54	½	Mulberry Fork of Black Warrior:		
Tallassee, Ala	20	¼	Cordova, Ala	50	½

The Sacramento and San Joaquin drain the Great Central Valley of California into Suisun Bay, the former bringing its water from the north, the other from the south. Karquines Strait connects Suisun Bay to San Pablo Bay and San Francisco Bay.

THE SACRAMENTO.

Its tributaries are the Feather, Butte Creek, Table Mountain Creek, Chico Pine, Dry Deer, Mud, Little Antelope, Big Antelope, and Salt.

THE SAN JOAQUIN.

Main tributaries are the Calaveras, Tuolumne, Orestimba, Merced, Fresno, and Kings River Slough.

THE COLUMBIA.

Main tributaries are the Willamette, in western Oregon; the Snake, in Idaho; the Kootenai, in Montana, and Lake Pend Oreille, in northern Idaho.

	Distance from Portland.
The Columbia:	*Miles.*
Northport	569
Wenatchee	359
Umatilla	187
The Snake:	
Weiser	427
Lewiston	393

NOTES ON RIVERS AND FLOODS.

The following notes on rivers and floods are furnished by Weather Bureau officials in charge of river stations:

ALBANY, N. Y.

By Mr. A. F. SIMS, *Observer.*

The fountain head of the Hudson River is a small pool on the southern slope of Mount Marcy, 4,326 feet above the sea, and known as Summit Lake, Summit Water, or Lake Tear of the Clouds.

The Hudson River from its source to its mouth lies within the deep valley which terminates the eastern table-land of the Appalachian system. On its watershed are mountain chains more or less isolated from each other and bearing the highest summits in the State. They are the Highlands, which cross the Hudson at the limit of the coast region; Shawangunk and Catskill Mountains on the western bank of the river, and the system of the Adirondacks covering the territory between the St. Lawrence and Champlain valleys.

The Hudson Valley region is a long, narrow strip of land on both sides of the Hudson, surrounded first by hills and low table-lands as far as the gorges, where the river crosses the Highlands.

The valley widens higher up into the extensive plains on the eastern side of the river.

Notwithstanding this low situation, its climate is severe, owing to the cold northern winds which blow from Canada and Labrador along the open valley of Lake Champlain.

The Mohawk Valley is a deep transversal cut; its river is the principal feeder to the Hudson north of Albany.

The principal water power in Albany County is supplied by the Mohawk River at Cohoes, N. Y. The Mohawk is about 175 miles long and drains a territory which is on an average 20 miles wide. The total drainage area is thus about 3,500 square miles.

The average volume of the Hudson at Albany, N. Y., is estimated to be 618,111 cubic feet per minute, equal to an average daily flow of 6,677,000,000 gallons, the minimum being 1,829,000,000 in July, and the maximum 12,330,000,000 in March.

AUGUSTA, GA.

By Mr. D. Fisher, *Observer.*

The following rain-reporting stations are now in operation in the up river country: Anderson, S. C., established January 13, 1892; Elberton, Ga., established December 1, 1891; Greenwood, S. C., established December 1, 1892; Mount Carmel, S. C., established January 13, 1892; Toccoa, Ga., established December 1, 1891; Washington, Ga., established December 1, 1891.

When the river is 10 feet or lower, the following average of rain throughout the upper valley will give a river as indicated below:

Inches of rain required in a given number of hours to produce different stages of the river.

Rainfall.	Number of hours.	Stage of river.	Rainfall.	Number of hours.	Stage of river.
Inches.		*Feet.*	*Inches*		*Feet.*
1.50	24	20.0	4.50	48	30.5
2.00	24	24.0	5.00	48	31.5
2.50	24	26.0	5.50	48	32.0
3.00	24	28.0	6.00	48	33.5
3.50	24	30.0	6.50	48	34.5
4.00	24	31.5	7.00	48	35.5
4.50	24	32.5	1.50	72	16.0
5.00	24	33.5	2.00	72	20.0
5.50	24	34.5	2.50	72	22.0
6.00	24	35.5	3.00	72	24.0
6.30	24	36.5	3.50	72	26.0
7.00	24	37.5	4.00	72	27.5
1.50	48	18.0	4.50	72	28.5
2.00	48	22.0	5.00	72	29.5
2.50	48	24.0	5.30	72	30.5
3.00	48	26.0	6.00	72	31.5
3.50	48	28.0	6.30	72	32.5
4.00	48	29.5	7.00	72	33.5

Discharge of the river at various stages.

	Cubic feet.
30 feet	89,000
35.1 feet	155,000
40.1 feet	370,000

Area of watershed above Augusta, 7,294 square miles. The above data were determined by myself after careful consideration of all facts and from surveys in 1888 and 1889, and are believed to be substantially correct, conflicting statements to the contrary notwithstanding.

[Correction by Mr. George W. Brown, civil engineer office, Florence, Ala.]

Height of zero of gauge above mean low water, Savannah, Ga., 103.82 feet; low water on gauge (since 1888), 5.8; highest water known, 38.7 feet (September 11, 1888); low water flow at Augusta, 3,800 cubic feet per second; high water discharge at Augusta (September 11, 1888), 305,000 cubic feet per second.

The following table shews the discharge of the river at Augusta, Ga., for various heights on the gauge (since 1888):

Height of river.	Discharge per second.	Height of river.	Discharge per second.
Feet.	*Cubic feet.*	*Feet.*	*Cubic feet.*
5	3,000	14	20,000
6	4,000	15	22,700
7	5,210	16	25,500
8	6,600	17	28,700
9	8,400	18	32,100
10	10,400	19	35,500
11	12,600	20	39,000
12	14,900	25	60,000
13	17,300		

ATLANTA, GA.

By Mr. George E. Hunt, *Local Forecast Official.*

Eight streams comprise the system of rivers under the regimen of the Atlanta station, viz: The Oostanaula, Etowah, Coosa, Chattahoochee, Flint, Ocmulgee, Oconee, and Altamaha.

The total length of these rivers aggregates about 1,600 miles; the total navigable length of all of them is about 800 miles, as follows:

Altamaha, length, 70 miles; navigable, 70 miles; basin area, including that of its two confluents, the Ocmulgee and Oconee, about 14,000 square miles.

Ocmulgee, length, 300 miles; navigable, 40 miles.

Oconee, length, 300 miles; navigable, 40 miles.

Chattahoochee, length, 450 miles; navigable, 300 miles; its basin area is about 6,900 square miles.

Flint, length, 300 miles; navigable, 250; basin area, about 9,500 square miles.

Etowah, length, about 100 miles; not navigable.

Oostanaula, navigable about 80 miles; the drainage area of the Oostanaula and Etowah combined is about 3,700 square miles.

To properly understand the above streams a glance at a topographical map of the State is necessary. A great ridge of hills or low mountains passes from north to south almost centrally through Georgia. This is a part of the long, irregular eastern edge of the great Mississippi Basin. A second ridge separates the Mississippi Valley from the Gulf Slope. This, the southern edge of the Mississippi Basin, also passes through the northern portion of Georgia, the two ridges meeting in the northeast corner of the State. It is said that at this critical point an umbrella held in a shower of rain sheds the water so that one part reaches the Atlantic near Savannah, a second part the Gulf at Apalachicola, while a third enters the Gulf below New Orleans, having passed through the Hiwassee, Tennessee, Ohio, and Mississippi rivers. It is thus seen that Georgia participates in three great basins, determined by the ridges of watersheds just described. Of her surface there are in the Atlantic Slope about 32,000 square miles, the Gulf Slope about 25,700 square miles, and the Mississippi Valley about 850 square miles, over one-half of her surface drainage flowing into the Atlantic.

The Coosa River, in the extreme northwest portion of the State, is formed at Rome by the junction of the Oostanaula and Etowah rivers, and flows due westward into Alabama, traversing but a single county in Georgia. The confluents of the Coosa, having the mountains of eastern Tennessee and north Georgia for watersheds, flow down almost as from the apex of a cone, and draining, as at least one of them does, a portion of north Georgia subject to an annual rainfall of over 60 inches, causes Rome to be the point most exposed to flood damage of all places in Georgia. In addition to the gauge at Rome this service has one on the Oostanaula, at Resaca, 30 miles above Rome, and another on the Etowah, at Canton, 48 miles above Rome. Rains at the head waters or along these streams affect the Coosa at Rome within twenty-four hours, and the maximum rise resulting from them usually occurs within forty-eight hours. It appears, from an examination of all the accessible data, that rises in the Oostanaula are more sudden than those in the Etowah, and that they reach Rome slightly in advance of those in the latter river. On December 26, 1894, heavy rains fell at voluntary State weather service stations located near the head waters of the Oostanaula. On the morning of that date the river at Resaca stood 2.1 feet on the gauge, and the Coosa at Rome 1.6 feet. By the morning of the 27th the Oostanaula had risen 11 feet at Resaca, and the Coosa 7 feet at Rome. By the morning of the 28th there was a further rise of 3 feet at Rome, while at Resaca the Oostanaula had begun to fall. During the period of the above changes in the Oostanaula the rise in the Etowah amounted to only 1 foot. This, however, is a very rare occurrence, both rivers usually rising at or near the same time as to make little difference in the effects of such rises upon the Coosa at Rome. In fact, in no instance do the records at this office show a rise of any consequence in one of these streams without a corresponding rise in the other. Their head waters are not very far apart, but while the Oostanaula flows almost due southward, the Etowah makes a grand sweep southward, after which it flows westerly, its course resembling somewhat an immense horseshoe. On the 9th and 10th of December, 1894, voluntary observers about the head waters and along both streams reported heavy rains. By the morning of the 29th the Oostanaula had risen over 9 feet at Resaca; the Etowah, at Canton, 6 feet 5 inches, and the Coosa, at Rome, 12 feet 4 inches. On the morning of the 13th the crest of the freshet had reached Rome, causing a further rise of 2 feet 6 inches in the Coosa at that point.

The Chattahoochee River has its source in the mountains of north central Georgia, flowing for the first hundred miles or over in a southwesterly direction along a narrow valley with mountainous watersheds on each side. From a point nearly due west from Atlanta its valley widens out to the east, the mountains on that side receding and dwindling into low hills, but on the west side its valley continues narrow, the river hugging the base of the mountains for a considerable distance farther south. Freshets occurring in the river north of Atlanta do but little damage, the valley being narrow and containing but little arable land. For quite a long stretch between Atlanta and the Alabama line the country along the river is flat and subject to damaging floods. It should be remembered that the Chattahoochee is the boundary line between the States of Alabama and Georgia for a distance of about half the length of the two States. From the Alabama line to Columbus, a distance of about 30 miles, there is a fall of 362 feet, making the river dangerous at and just below the latter place. This service has three gauges on the Chattahoochee; the first at Whitesburg, about 40 miles below a point 7 miles due west of Atlanta; the second at Columbus, 80 miles below Whitesburg; and the third at Eufaula, Ala., about 50 miles below Columbus. Rains at Atlanta and along the water sheds north of that city cause a rise at Whitesburg within from sixteen to twenty-four hours, and the crest of the freshet always passes from Whitesburg to Columbus within less than twenty-four hours, and from Columbus to Eufaula in considerable less time than twenty-four hours. The river seldom overflows its banks in the vicinity of Eufaula, but damaging floods occur both above and below that place.

The Flint River rises in western Georgia, just south of the source of the Chattahoochee, emptying into the latter stream in the extreme southwest corner of the State. This service has three gauges on the Flint, the first being at Reynolds, a point located about 100 miles south of its source, the second at Albany, 80 miles below Reynolds, and a third at Bainbridge, 60 miles below Albany. Rains about the headwaters of the Flint affect the gauge readings at Reynolds within twenty-four hours, but from that point to Albany the current is sluggish, and the crest of a freshet is generally two days in passing to Albany, and much longer than that when the floods are very high. There is no instance on record when the maximum effects of a freshet were noted at Albany within less than four days after being reported at Reynolds. The crest of a freshet is about twenty-four hours in passing from Albany to Bainbridge.

The Altamaha River is formed in the southeastern portion of the State by the junction of the Ocmulgee and Oconee rivers. It is a navigable stream 70 miles long. As this service has no gauge on the Altamaha, it is impossible to estimate the effects upon it of freshets in its confluents. The course of the Altamaha is southeastward through a very flat section of the State.

The Ocmulgee River rises in north central Georgia, about 50 miles northeast of the source of the Flint River. The only gauge the service has on this stream is at Macon, a place about half the distance between its source and junction with the Oconee. Rains about its headwaters affect the gauge at Macon within twenty-four hours. The country through which this river flows is very flat, and except the country along the Coosa, at Rome, experiences the most damaging floods in the State. The rises at Macon are unusually sudden, frequently doing much damage in that city. Last January there was a rise at Macon of 12 feet within less than sixteen hours. The falls are as rapid as the rises.

The Oconee River rises about 40 miles east of the source of the Ocmulgee and flows southerly, almost parallel with that stream, to the point of their junction. The only gauge on the Oconee is at Dublin, about 40 miles above its junction. Rains along its headwaters cause a rise at Dublin within twenty-four hours, the maximum effects of such rains, however, not occurring until four days after anything like general rains have ended. The danger line at Dublin is 17 feet on the gauge.

The danger lines, high-water marks, etc., as published in "Daily river stages at river gauge stations on the principal rivers of the United States for the years 1890–92, Part IV," remain unchanged.

The most dangerous periods on all the rivers in Georgia are during the spring and early summer, and the crops most damaged are corn and cotton. In the northern portion of the State floods frequently delay the planting of corn and other early crops.

CAIRO, ILL.

By W. T. Blythe, *Local Forecast Official.*

Approaching Evansville from the south, the Ohio River makes a sharp curve and runs southeast from that city about 4 miles, then curves southeasterly 4 miles, south 1 mile, southwest 5 miles, northwest 2 miles, north by east 4 miles to Cypress Bend, where a sharp curve is made to west by south. (From a point about 4 miles below Evansville to Cypress Bend, the air-line distance in a southwest direction is about 3 miles, while the distance by river is about 17 miles.) From Cypress Bend to Walnut Bend, 9 miles, or 3 miles below foot of Diamond Island, the course is west by south; from Walnut Bend to Mount Vernon, 5 miles, northwest; from Mount Vernon to Uniontown, Ky., about 13 miles, south by west; and from Uniontown to mouth of Wabash River, 6 miles, northwest; from the mouth of the Wabash River southwest, 13 miles; thence south by east to Tradewater Bar, 12 miles; there it curves southwest to Weston, Ky., 2 miles; from Weston, Ky., its course is almost due west to Elizabethtown, Ill., 13 miles; from Elizabethtown, southwest, 4 miles to Irish Jimmies Bar; thence northwest 3 miles to Grand Pier Bar; from Grand Pier Bar, southwest, 4 miles; thence south by west, 8 miles, to Sisters Island; thence south by east to the mouth of the Cumberland River at Smithland, about 11 miles; from Smithland, southwest, 6 miles; thence northwest passing Paducah, Ky., and Brooklyn, Ill., to head of Grand Chain, a distance of 30 miles; from the head of Grand Chain its direction is southwest, passing Caledonia, Ill., 8 miles, Mound City, Ill., 16 miles, to a point 4 miles below Mound City and 1 mile above Cairo, where it curves to the south and easterly, passing Cairo, and empties into the Mississippi 1 mile below Cairo, running southeast.

PRINCIPAL AFFLUENTS OF THE OHIO RIVER BELOW CINCINNATI, OHIO.

Kentucky River enters at Carrollton, Ky., about 60 miles above Louisville. Its north and south forks rise in the Cumberland Mountains and unite at Proctor, Ky. Its length, exclusive of branches, is estimated at 250 miles, or, including the North Fork, about 350 miles.

Green River, Kentucky, which is about 350 miles long, navigable for small steamboats for about 150 miles from its mouth, and drains the greater portion of central Kentucky, empties into the Ohio 8 miles above Evansville. (The greatest length of Green River is erroneously stated in Annual Report Chief Signal Officer, 1891, page 222, to be 175 miles.)

The rivers and principal creeks emptying into the Ohio River below Evansville are:

Highland Creek, Kentucky, 48 miles below Evansville and 1 mile above Uniontown, Ky.

Wabash River, 54 miles below Evansville, 19 miles below Mount Vernon, Ind., and about 10 miles above Shawneetown, Ill. The Wabash River is about 550 miles long, is navigable to Vincennes, a distance of about 140 (?) miles from its mouth, and drains a large portion of eastern part of Illinois, three or four counties in northwestern Ohio, and nearly the whole State of Indiana.

Saline River, Illinois, 9 miles below Shawneetown, Ill., and 3 miles above Caseyville, Ky.

Tradewater River, Kentucky, 2 miles below Caseyville, Ky., and 2 miles above Weston, Ky. The Tradewater drains parts of Caldwell, Hopkins, Crittenden, and Union counties, Ky.

Big Cane Creek, Illinois, 2 miles below Weston, Ky., and 3 miles above Cave In Rock, Ill.

Big Creek, Illinois, 8½ miles below Cave In Rock, Ill., and one-half mile below Elizabethtown, Ill.

Big Bay Creek, Illinois, 20 miles below Elizabethtown, Ill., 8 miles below Golconda, Ill., and 1 mile above Bay City, Ill.

Cumberland River, Kentucky, at Smithland, Ky., 9 miles below Bay City, Ill., 2 miles above New Liberty, Ill., about 10½ miles above the mouth of the Tennessee River, and about 12 miles above Paducah, Ky. The Cumberland is one of the largest affluents of the Ohio River. It rises in Harlan County, Ky., and runs toward nearly every point of the compass except east. It intersects several counties in Kentucky and flows from Cumberland County southwestward to middle Tennessee, in which it runs nearly westward to Nashville. Below Nashville its general direction is northwestward, and reenters Kentucky from Stewart County. Its length is estimated at 650 miles. Steamboats ascend it to Nashville, 192 miles from its mouth, and it is navigable during high water for a considerable distance above Nashville.

Tennessee River, about 1½ miles above Paducah, Ky. The Tennessee River is formed by the Clinch and Holston rivers, which rise in Virginia and unite at Kingston, Roane County, Tenn. It flows southwestward to Chattanooga, where it turns abruptly to the right and runs nearly north about 40 miles, where a mountain range changes its course to the southwest again to Guntersville, Ala. Below this point it pursues a west-northwest direction until it touches the State of Mississippi. It next bends to the right, returns to the State of Tennessee, runs northward, enters Kentucky at the southeast corner of Trigg County and the Ohio River near Paducah. It is the largest affluent of the Ohio and is about 800 miles long, excluding branches. Large steamboats ascend the Tennessee to Hamburg, Tenn., 233 miles above its mouth, all the year, and to Florence, Ala., about 65 miles farther, except during very low water. Big Bend Shoals, Big Tree Shoals, and Colbert Shoals, between Hamburg, Tenn., and Florence, Ala., make navigation unsafe and at times impracticable during low-water periods. Above and near Florence navigation is obstructed by rocky rapids called Muscle Shoals. Above Muscle Shoals the river is again navigable for steamboats to Kingston, Tenn. It has an affluent called the Little Tennessee, about 150 miles long, which rises near the north border of Georgia and runs northward through Macon County, N. C., turns westward, passes into Tennessee, and enters the Holston River about 7 miles above London, Tenn. Another affluent is Clarks River, Kentucky, about 75 miles long; empties into the Tennessee about 1 mile above its mouth.

Island Creek, Kentucky, enters the Ohio River one-half mile above Paducah.

Perkins Creek, Kentucky, 5 miles below Paducah and 2 miles below Brooklyn, Ill.

Seven Mile Creek, Illinois, at Belgrade, Ill., 6 miles below Paducah and 3 miles below Brooklyn, Ill.

Massac Creek, Illinois, 1½ miles below Belgrade, Ill., and 2 miles above Metropolis, Ill.

Massac Creek, Kentucky, 1½ miles below Metropolis, Ill.

Little Run Creek, Kentucky, 3 miles below Metropolis, Ill., and 2 miles above Little Chain.

Hunting or Redstone Creek, Kentucky, 19 miles below Paducah and 4 miles above Head of Grand Chain.

Humphries Creek, Kentucky, 10 miles below head of Grand Chain, 8 miles below Grand Chain Landing, Ill., 5 miles below foot of Grand Chain, 2 miles below Caledonia, Ill., and 6 miles above Mound City, Ill.

Cache River, Illinois, 1 mile below Mound City, Ill., and about 4 miles above Cairo, Ill. The Cache is about 70 miles long and drains part of Johnson, Pulaski, and Alexandria counties, Ill.

ISLANDS, BARS, AND OTHER OBSTRUCTIONS IN THE OHIO RIVER BETWEEN EVANSVILLE, IND., AND CAIRO, ILL.

Henderson Towhead, head 7 miles and foot 9 miles below Evansville and 1 mile above Henderson, Ky.

Henderson Island, head 1 mile and foot 2 miles below Henderson, Ky.

Diamond Island, head near West Franklin, Ind., 13 miles below Henderson, Ky., foot 3 miles below West Franklin and 8 miles above Mount Vernon, Ind.

Slim Island, head 3 miles and foot 7 miles below Mount Vernon, Ind.

Mississippi Bar, head 9 miles and foot 11 miles below Mount Vernon, Ind.

Upper Highland Rocks (right bank), 12 miles below Mount Vernon and 1 mile above Uniontown, Ky.

Lower Highland Rocks (left bank), 2 miles below Uniontown, Ky.

Wabash Island, opposite mouth of the Wabash River, the head 4 miles and foot 8 miles below Uniontown, Ky., and 8 miles above Shawneetown, Ill.

Browns Island, 3 miles above Shawneetown, Ill.

Cincinnati Towhead, 6 miles below Shawneetown, Ill.

Saline Bar and Saline Towhead, opposite and above mouth of Saline River, 8 miles below Shawneetown.

Blakeleys Bar and Blakeleys Towhead, 11 to 12 miles below Shawneetown and 1 mile above Caseyville, Ky.

Caseyville Bar, opposite Caseyville, Ky.

Tradewater Bar, opposite mouth of Tradewater River, and 1 to 2 miles below Caseyville, Ky.

Towhead, one-half mile below mouth of Tradewater River.

Cave in Rock Island, head 6½ miles and foot 7½ miles below Caseyville, and one-half mile above Cave in Rock, Ill.

Walkers Bar, 3 miles below Cave in Rock, Ill.

Half-Moon Bar, 3 to 5 miles below Cave in Rock, Ill.

Hurricane Island Towhead, 4½ miles below Cave in Rock, Ill.

Hurricane Island, head 4½ miles and foot opposite Elizabethtown, Ill., 8 miles below Cave in Rock.

Irish Jimmies Bar, 4 to 5 miles below Elizabethtown, Ill.

Grand Pier Bar, opposite mouth of Grand Pier Creek, 8 miles below Elizabethtown, Ill.

Randolph Island, 3 to 4 miles below mouth of Grand Pier Creek and foot 1 mile above Golconda, Ill.

Pryors Island, head 2½ miles and foot 4 miles below Golconda.

Loose Rocks (near right bank), 2½ to 3 miles below Golconda, Ill.

Sisters Island, head 6 miles and foot 7 miles below Golconda, Ill., and 2 miles above Bay City, Ill.

Stewarts Island, head 2 miles below Bay City, Ill., and foot opposite Birds Point Landing, Ky., 3¾ miles below Bay City.

Dog Island, 4 to 5 miles below Birds Point Landing and 1 mile above the mouth of the Cumberland River, at Smithland, Ky., which is opposite Hamlettsburg, Ill.

Cumberland Island extends from one-half mile above mouth of Cumberland River to near New Liberty, Ill., 2 miles below.

Hamlettsburg Bar lies opposite the village of Hamlettsburg and between it and Cumberland Island.

Towhead, opposite New Liberty, Ill., 2 miles below mouth of Cumberland River.

Cottonwood Bar, opposite mouth of Caney Creek, Kentucky, 4 to 5 miles below Smithland, Ky., and 7 to 8 miles above Paducah, Ky.

Indiana Bar, 4½ miles above Paducah, Ky.

Tennessee Island, about 1 mile long, from opposite mouth of Tennessee to opposite Paducah.

Sand Bar, about 1 mile long, opposite Paducah, Ky.

Belgrade or Fort Massac Bar, opposite the village of Belgrade, Ill., 6 miles below Paducah, Ky., and 2 miles above Metropolis, Ill.

Little Chain (rocks), 4 to 5 miles below Metropolis, Ill.

Grand Chain (of rocks) extends from "head," near Wilkinsons Landing, 13 miles below Metropolis, to "foot," near Barbers Landing, 2½ miles above Caledonia, Ill., or a distance of about 6 miles.

Wreck of *Northerner* and wreck of *Suwanee*, at foot of Grand Chain, one-fourth to one-half mile above Barbers Landing, Ill.

Cache Island, near left bank and Mound City Towhead near right bank, from 5½ to 7 miles below Caledonia, Ill., and from 1½ above to opposite Mound City, Ill.

Weston Rock, at the mouth of the Ohio River, about 1 mile below Cairo.

Two railroad bridges cross the Ohio below Evansville, viz, that of the Louisville and Nashville at Henderson, Ky., and of the Illinois Central, 1 mile above Cairo.

LANDS SUBJECT TO OVERFLOW AT CERTAIN STAGES, MEASURED ON THE WEATHER BUREAU GAUGES MAINTAINED AT EVANSVILLE, MOUNT VERNON, MOUNT CARMEL, PADUCAH, AND CAIRO.

At 30 feet on the Evansville gauge, the water begins to leave the river banks and spread over the lowlands on both sides of the river. At 36 feet a current sets in from a point about 4 miles below Evansville to Cypress Bend, about 3½ miles distant, in a southwest direction, where it reenters the river 17 miles below by the main channel. At 40 feet all the low farming lands, embracing large areas on both sides of the river above and below Evansville, are said to be submerged.

Mount Vernon, Ind., is 36 miles, by river, below Evansville. It is above the highest stages on record. But in its immediate vicinity, on both sides of the river both above and below, there are large areas of improved and highly productive farming land, which are subject to overflow at 28 feet and upward on the Mount Vernon gauge, provided the stage at Mount Carmel, Ill., on the Wabash River, is at the same time 15 feet or more.

Stages of from 33 to 37 feet at Cincinnati, dependent upon the amount of water coming out of the Kentucky, Green, and Wabash rivers, give 28 feet and upward on the Mount Vernon gauge three to four days after the above readings are observed at Cincinnati, and 40 feet at Cincinnati with a simultaneous stage of 15 feet or upward at Mount Carmel, it is said by old residents of Mount Vernon, floods the lowlands between West Franklin, 12 miles above, and Mount Vernon, also a large area in Henderson County, Ky., opposite Mount Vernon, and nearly the whole of Point Township, Posey County, Ind., containing 32,000 acres, rated with the best producing land in the State, and which lies in the crotch between the Ohio and Wabash rivers.

In addition to the above, there are also extensive tracts of improved land on both sides of the Wabash River from its mouth to above Mount Carmel, Ill., which are inundated at stages of 15 feet at Mount Carmel and 28 feet at Mount Vernon.

From Shawneetown to Paducah no specific, reliable information has as yet been obtained as to districts subject to overflow, but it is believed that the areas are small and that the damage likely to ensue is also comparatively small.

At 37 feet on the Cairo gauge the river begins to leave its banks about 20 miles below Paducah and runs across the lowlands to Fort Jefferson, Ky., about 6 miles below Cairo on the Mississippi River. At 40 feet on the Cairo gauge the entire country, except the Illinois Central Railroad and Mobile and Ohio Railroad embankments, east of the river and west of a line drawn from 20 miles below Paducah to Fort Jefferson is covered with water. At 40 feet on the Cairo gauge the Mississippi is also running over its banks at Birds Point, Mo., and with higher stages the water rapidly spreads over hundreds of square miles in Mississippi, Scott, Stoddard, and other counties south of them in Missouri.

CINCINNATI, OHIO.

By Mr. S. S. Bassler, *Local Forecast Official.*

It is well known that a good rise out of the Alleghany will give river men fully double the time that an equal rise out of the Monongahela does.

The upper Ohio being a known quantity, the Kanawha is watched more closely than when its surprises are expected. Streams flowing into the Ohio from the north do not affect it as quickly as those flowing into it from the south.

The Muskingum is a sluggish stream as compared with the southern tributaries.

Although the Scioto sometimes brings a great deal of water, it is also a sluggish stream and little attention is paid to it.

The Kanawha of all the southern tributaries carries the most water, and is considered the most important factor in Ohio River rises.

Touching the estimates made as to the stage of water in consequence of a certain stage at any point above, it is believed that such estimates are simply guesswork. There is seldom any agreement on the probable stage.

CHARLESTON, S. C.

By L. N. Jesunofsky, *Local Forecast Official.*

The South Carolina river service, as at present organized, comprises nine stations, as follows: Camden, S. C., on the Wateree River; Cheraw, S. C., on the Great Pedee River; Columbia, S. C., on the Congaree River; Conway, S. C., on the Waccamaw River; Edisto, Barnwell County, S. C., on the Edisto River; Effingham, S. C., on the Lynch River; Fairbluff, N. C., on the Lumber River; Kingstree, S. C., on the Black River; St. Stephens, S. C., on the Santee River.

Observations on the stages of water, the state of weather, wind directions, and measurements of precipitation are made daily at 8 a. m. during the flood seasons—January to March, inclusive, and July to October, inclusive—and sent by mail upon a printed card provided for the purpose.

When rainfall of 1 inch or more occurs, and the rivers have risen 6 feet or more during the preceding twenty-four hours, the observations are then sent by telegraph to the Charleston, S. C., center. At the end of the month the daily observations are tabulated upon a form and sent to the section center, where they are verified, and then transmitted to the chief of the Weather Bureau. The daily river reports are embodied in a table which appears regularly upon the daily weather chart issued from this station. The data from this table is then transcribed upon small blanks for publication in the Daily News and Courier of Charleston, S. C.

When floods are imminent telegrams and postal cards are forwarded to 43 towns along the streams mostly affected.

All streams over the coast region of this State east and south of lines drawn from Barnwell, Barnwell County, to Vance, Orangeburg County, to Camden, Kershaw County, and thence over to Cheraw, Chesterfield County, are subject to overflow, causing much inconvenience to traffic, loss of live stock, and injury to crops. West and north of this boundary the contour changes to a decided elevation, and freshets are less frequent than over the coast region.

With imperfect data as to the width and drainage area, the method of forecasting floods in South Carolina is, as yet, somewhat crude. We know approximately the area of the Santee, Pedee, and Waccamaw River basins. Very good results have, however, followed the systematic study of rainfall measurements with regard to the volume of water in the upper streams and the rate of increase in the lower streams.

Each stream will be treated upon separately in this paper, as no single rule, except as to variable rainfall measurements, applies to all.

THE WACCAMAW RIVER BASIN.

Length of the Waccamaw River above Conway, S. C., 151 miles; length of the Waccamaw River below Conway, S. C., 63 miles; drainage area above Conway, S. C., 1,140 square miles; drainage area below Conway, S. C., 432 square miles. The drainage area is combined with that of the Great Pedee basin for 20 miles above Winyah Bay. It extends for about 5 miles westward along the stream above the junction of the Waccamaw and Great Pedee rivers, and continues for 5 miles west of the stream, until it reaches the State line; the area then narrows down considerably, until within a short distance of Lake Waccamaw, in North Carolina, near the head waters of the Waccamaw River. The eastern limit of the Waccamaw basin embraces nearly all of that territory adjoining the Atlantic, curving westward toward the river at Nixonville, S. C., for about 3 miles. The line follows the eastern limits of the Caw Caw, the Green, and Big swamps, in North Carolina; thence northward, close to the Cape Fear River drainage area, and westward to Rosendale, Columbus County, N. C., where it terminates.

The gauge station within the Waccamaw basin is located at Conway, S. C. The gauge was formerly used by the United States Engineer Corps. It was repaired by the United States engineer and placed at the disposal of the Weather Bureau in November, 1893. Length of gauge, 10 feet; width, 0.6 foot; thickness, 0.1 foot. Gauge painted white; graduations in feet and tenths, and painted black. Position of gauge, Conway Toll Bridge pier; elevation of zero of river gauge above sea level, 25 feet; width of river at Conway, 285 feet; flood or danger line, 7 feet; river overflows at 8 feet; territory overflown at this gauge reading, 5 miles; highest water known; equal to reading on gauge, 9 feet, February 9, 1895; lowest water known, equal to reading on gauge, 0.0 feet, August 16, 1889. Owing to its low elevation and the small rate of descent, the Waccamaw at Conway rarely rises over 1 foot in twenty-four hours. It may have an almost uniform rise of 4 inches per day for about five days, and then begins to recede slowly, unless checked in its downward tendency by additional heavy rainfall, in which case the rate of increase is exceedingly small. During heavy rainfalls at Conway, S. C., the rise in the stream seldom exceeds 6 inches per day for one day or more than two days. This is due to the fact that the water spreads over a larger territory, not being confined within the river's banks.

With a rainfall of 2 inches reported from Fairbluff, N. C., near the western edge of the upper Waccamaw basin, the wave crests usually reach Conway, S. C., in three and a half days. The rising waters require an additional period of two and a half days before reaching Winyah Bay.

The Waccamaw River is navigable for 7-foot draft boats to Conway. Beyond Conway the depth is less, though steamers drawing 3 to 4 feet run to a point 40 miles above that town at possibly the lowest stages of water The river has its chief source in Waccamaw Lake, North Carolina, and after flowing in a southwesterly direction, approximately parallel to and not far from the seacoast, empties into Winyah Bay, at Georgetown, S. C. The lake is a body of fresh water about 3 miles wide and 5 miles long, with a probable average depth of 8 feet, situated on the line of the Wilmington, Columbia and Augusta Railroad, about 25 miles west of Wilmington, N. C. The total length of the river is about 214 miles, and the distance from head to mouth, by a straight line, would probably be 80 miles. There is very little current on the lower Waccamaw, but a much greater velocity is found in the upper portion.

The river reports from Conway, S. C., are principally used by steamboat men, stock breeders, lumbermen, and rice planters.

THE PEDEE BASIN.

There are four drainage areas within the Great Pedee basin, namely, the Little Pedee, the Great Pedee, the Lynch, and the Black.

LITTLE PEDEE BASIN.

The Little Pedee basin runs almost parallel with the river on both sides, its width averaging about 5 miles. It empties into the Great Pedee at Port Harrelson. The Lumber River, in North Carolina, is a continuation of the Little Pedee.

The gauge station within the Little Pedee basin is located at Fairbluff, N. C., on the Lumber River. Length of the Little Pedee River above Fairbluff, N. C., 102 miles; length of the Little Pedee River below Fairbluff, N. C., 86 miles; drainage area above Fairbluff, N. C., 410 square miles; drainage area below Fairbluff, N. C., 330 square miles.

The river gauge was erected in December, 1893, and is the property of the Weather Bureau. Length of gauge, 9 feet; width, 0.8 foot; thickness, 0.1 foot. Gauge is painted white; graduations painted black, in tenths of feet, the whole feet being represented by brass figures.

Position of gauge: On west side, central pier, of Fairbluff (N. C.) free bridge; Elevation of zero of river gauge above sea level, 59 feet; width of river at Fairbluff, N. C., 270 feet; flood or danger line, 6.5 feet; river overflows at 7 feet; territory overflown at this gauge reading, 2 miles; highest water known, equal to reading on gauge, 9 feet, March, 1848; lowest water known, equal to reading on gauge, 0.0 feet, June 1, 1893.

The rise of water in this stream at any gauge reading does not exceed 1¼ feet in twenty-four hours. With a rainfall of about 1 inch reported from Cheraw, S. C., near the head waters of the Little Pedee, or Lumber River, at a moderate stage, this stream will rise 3 to 4 inches per day for about five days. If the rainfall continues over the upper portion of this basin for a few days, and increases 1 inch or more for each day, the rate of rise in the stream is much greater, although the depth of water does not increase to a much greater extent, as it spreads over a much larger area, oftentimes for 3 miles on each side of the river.

It requires three days for the wave crests to reach Fairbluff, N. C., from the head waters. Within another three days' interval the advancing volume of water merges with the Great Pedee a few miles above Port Harrelson, S. C.

This stream is navigable for 3-foot draft vessels from Port Harrelson, S. C., to Fairbluff, N. C., at an ordinary stage of water.

Stock breeders, raftsmen, lumbermen, and steamboat men are greatly interested in the gauge readings reported from Fairbluff, N. C.

THE GREAT PEDEE BASIN.

The Great Pedee, emptying into Winyah Bay, Georgetown, S. C., has, including its upper portion, called the Yadkin, a total length of about 465 miles and a combined drainage area of 16,329 square miles, including the drainage area of its main tributaries, the Little Pedee, the Lynch, and the Black rivers. At a stage of about 0.5 foot above low water the discharge at Cheraw is about 7,000 cubic feet per second.

The stream is navigable for boats of 9 feet draft from Winyah Bay to Smith's Mills, 78 miles; thence navigable for boats of 3.5 feet draft to Cheraw, S. C., for 93 miles.

The river changes its name from that of Great Pedee to that of the Yadkin at the entrance of the Uharie, or Narrows, in North Carolina, 71 miles above Cheraw, S. C. This river, above the Narrows, is about 200 miles long, with a drainage area of about 4,320 square miles, and nearly 600 feet wide; dropping to 40 to 50 in its 2-mile passage through the Narrows, and expanding again to about 500 feet in width at the lower end of the Narrows, with an outflow of 2,500 cubic feet of waterpower per second at low water, and rising to 12 feet in height during freshets. From the Narrows it flows in a general southerly direction for 71 miles before it reaches Cheraw, the present head of steam navigation. From Cheraw to the Narrows the elevation increases rapidly. From the State line, 13 miles up, to the Carolina Central Railroad the river surface has a rise of 37 feet, and a tolerably uniform slope of 2.8 feet to the mile. From the Carolina Central Railroad, 51 miles up, to the Narrows the river surface has a rise of about 310 feet, and a tolerably uniform slope of over 5.5 in addition to two special rapids (Bluetts Falls and Grassy Island Shoals) of 4 miles total length, and 10 feet rise per mile. A slope of 5.5 per mile is much greater than can be safely ascended by shallow-draft boats.

The Great Pedee runs in a southeasterly direction from Cheraw, S. C., to Port Harrelson, S. C., near the mouth of the Little Pedee. The lower section of this stream runs almost in a southerly direction from Port Harrelson to Winyah Bay. From Cheraw, S. C., to Georgetown, S. C., at the head of Winyah Bay, the river has an average slope of one-half foot to the mile.

The gauge station on the Great Pedee is located at Cheraw, S. C. Length of the Great Pedee above Cheraw, S. C., 294 miles; length of the Great Pedee below Cheraw, S. C., 171 miles; drainage area of the Great Pedee above Cheraw, S. C., 9,045 square miles; drainage area of the Great Pedee below Cheraw, S. C. including the Little Pedee, the Lynch, and the Black systems, 7,284 square miles.

The river gauge was erected in 1887 by the United States Engineer Corps, and placed in possession of the Weather Bureau in May, 1891. Length of gauge, 38 feet; width, 1 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in feet and tenths. Position of gauge: on Cheraw toll bridge, east central pier. Elevation of zero of river gauge above sea level, 50 feet. Width of river at Cheraw, S. C., 450 feet; flood or danger line, 27 feet; river overflows, at this gauge reading, on west side at 26 feet; on east side at 31.6 feet. Territory overflown at these gauge readings: At Cheraw, S. C., for one-half mile above and for 10 miles below Cheraw. Highest water known, equal to reading on the gauge, 37.3 feet, March 11, 1875; lowest water known, equal to reading on the gauge, 0.0 feet, August, 1866.

There is no stream in the State which rises more uniformly, with certain rainfall supply, than the Great Pedee at and above Cheraw, S. C. The precipitation measurements of Charlotte, N. C., are true indexes of what may be expected in the way of height of wave crests when reaching Cheraw. A 1-inch rainfall reported from Charlotte, N. C., most invariably causes the stream at Cheraw to rise 8 to 12 feet, and a 2-inch rainfall 12 to 22 feet. Quite satisfactory rain forecasts for the Great Pedee were made upon this basis. Observations from the special rainfall station at Salisbury, N. C., on the upper Great Pedee, made during 1893 and 1894, would seem to bear out these facts.

We are told by the United States Engineer Corps, which made surveys of this stream in 1876, 1879, and 1888, particularly between Cheraw, S. C., and the Narrows in North Carolina, close to the Uharie River, with a view to developing its immense water powers, that there are three large and natural waterfalls, over 40 feet in height, within a range of 21 miles, and that the slope for a distance of 71 miles above Cheraw is 355 feet, or an average of 50 feet to the mile. At the Narrows, on the Yadkin (which is an extension only of the Great Pedee), the amount of fall is 40 feet in 2 miles. At Grassy Island Rapids, 281 miles from and 180 feet above the Atlantic, the fall is 30 feet in 3 miles. At Bluett Falls, 279 miles from and 150 feet above the Atlantic, the fall is 12 feet in 1 mile. From this data it will be seen that the water descends with terrific force seaward, from the Narrows toward Cheraw, S. C. The stream at Cheraw has been known to rise 26.5 feet in sixteen hours. It frequently rises 20 feet or more in twenty-four hours, and has been known to decline 18 to 22 feet within the same time.

The wave crests on the upper Great Pedee reach Cheraw, S. C., in three days from the commencement of the rise to the time of falling. Below Cheraw conditions are somewhat different. It requires eight and a half days for the water to reach Georgetown, S. C., at the head of Winyah Bay, from Cheraw, S. C., where the drainage arises from the Great Pedee alone. When precipitation occurs over the entire basin of the Great Pedee, the waters of the Little Pedee, the Lynch, and the Black unite slowly with the Great Pedee and produce considerable of a freshet at the head of Winyah Bay.

Occasionally a second rise in the Great Pedee at and above Cheraw, S. C., following close after the first, may overtake the first rise on its oceanward voyage, and cause the stream near Georgetown, S. C., to remain at a higher stage for a greater period than is ordinary. During the rice-growing season, when the freshets meet the maximum tides, much rice is injured thereby.

Two-thirds of the timber cut upon the Great Pedee and its tributaries is sent in rafts to Georgetown, S. C., where it is carried to the mills. The river reports above Georgetown form an important item in the lumberman's business. Without them they could not prepare their logs in time for rafting out of the swamps. The reports also enable stockmen to protect their cattle from sudden rises. Steamboat men regulate the size of their cargoes by the information contained in the river observations from Cheraw, S. C., and other stations along the tributaries of the Great Pedee. The downward freights are cotton, spirits of turpentine, rosin, tar, rice, timber, cypress lumber, and shingles. The upward freights are fertilizers and general merchandise.

THE LYNCH RIVER BASIN.

The Lynch River is the smallest of the three tributaries belonging to the Great Pedee. It empties into the Great Pedee 30 miles below Effingham, S. C., and runs in a southeasterly course from its headwaters at the State line to its confluence with the Great Pedee. Its rate of slope is relatively small, being about 6 inches to the mile from the State line to Tillers Ferry, S. C., and averaging 4 inches to the mile from Tillers Ferry, to Effingham, S. C., and below.

On account of its elevation the stream rises much faster at Tillers Ferry, S. C., than at Effingham, S. C. During heavy rainfalls the greatest rate of increase is 3 feet per day at Tillers Ferry, while at Effingham, S. C., it seldom rises 1.4 feet in any twenty-four hours.

The effect of rainfall at Cheraw, S. C., and Camden, S. C., bears a wonderful influence upon the drainage system of the Lynch River. One-inch rainfalls at Camden, S. C., may produce a rise of 2 to 4 feet in about three days at Effingham, S. C. As a rule the water recedes very slowly at and below Effingham, S. C., due doubtless to its close proximity to the waters of the Great Pedee, which serves as a check to its downward progress.

The gauge station within the Lynch basin is located at Effingham, S. C.

Length of the Lynch River above Effingham, S. C., 75 miles; length of the Lynch River below Effingham, S. C., 30 miles; drainage area of the Lynch River above Effingham, S. C., 335 square miles; drainage area of the Lynch River below Effingham, S. C., 110 square miles.

The river gauge was erected in May, 1891, and is the property of the Weather Bureau. Length of gauge, 20 feet; width, 0.4 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in feet and tenths. Position of gauge, 6 feet on upright support; extension of 14 feet on large tree. Elevation of zero of river gauge above sea level, 65 feet; width of river at Effingham, S. C., 120 feet; flood or danger line, 12 feet; river overflows at 12 feet; territory overflown at these gauge readings, one-half mile. Highest water known, equal to reading on the gauge, 17.5 feet, January 24, 1892; lowest water known, equal to reading on gauge, 0.0 foot, 1884.

The stream is navigable for 3-foot draft boats from its mouth at the Great Pedee to Effingham, S. C.

The principal industry on the Lynch River is log rafting, which begins in September and ends in April. The river reports from Effingham are also used extensively by the rice and cotton planters on the Great Pedee, near the mouth of the Lynch River.

THE BLACK RIVER BASIN.

This stream is one of the tributaries of the Great Pedee. Navigation is uninterrupted for light-draft steamers between the mouth of the Great Pedee and Kingstree, S. C., on the Northeastern Railroad, except during the low-water season in the summer months, when but few steamers ply up this stream. Much lumber is rafted upon the upper Black River. On the lower Black River rice, cotton, and naval stores are shipped in large quantities, and stock breeders suffer greatly during freshets.

The rainfall at Camden, S. C., affects the gauge readings at Kingstree, S. C. A 1-inch rainfall at that place will cause a rise of about 1½ feet at Kingstree. A 2-inch rainfall at Kingstree elevates the stream but a few inches there. The greatest danger from overflow occurs some 45 miles below Kingstree, near the mouth of the Black, where the river is much wider than above stream. The backing tide water from Wingate Bay, the freshets from the Great Pedee, together with the rising waters from the Black and Waccamaw, form a continuous sheet of water for many miles, and oftentimes cause great loss to crops and other products. This danger has been avoided to a large extent since the river service of the Bureau has been in operation.

There is one river-gauge station within the Black River basin, located at Kingstree, S. C. Length of the Black River above Kingstree, 64 miles; below Kingstree, 52 miles. Drainage area of the Black River above Kingstree, 301 square miles; below Kingstree, 168 square miles.

The river gauge was erected in December, 1893; it is the property of the Bureau. Length of gauge, 15 feet; width, 0.8 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in tenths of feet, the whole feet being represented by brass figures. Position of gauge, on middle south pier of Kingstree free bridge. Elevation of zero of gauge above sea level, 37 feet; width of river at Kingstree, S. C., 250 feet; flood or danger line, 12 feet; river overflows at 14 feet; territory overflown at three gauge readings, 3 miles west and south of Kingstree. Highest water known, equal to reading on the gauge, 14.5 feet, September, 1893; lowest water known, equal to reading on the gauge, 0.0 foot, May, 1888.

THE SANTEE RIVER BASIN.

The Santee River, formed by the Congaree and Wateree rivers, has, from the sea to its headwaters in the mountains, a total length of about 500 miles, and a drainage area of about 15,414 square miles. The river is connected by canal, to Winyah Bay, through a portion of Mosquito Creek.

The Congaree River, formed by the Broad and Saluda rivers, and itself uniting with the Wateree to form the Santee, has, from the headwaters of its tributaries in the mountains to its mouth in the Santee, a total length of about 250 miles, and a total drainage area of about 8,312 square miles. The name Congaree applies therefore to 50 miles of river from the confluence of the Broad and Saluda, just above Columbia, S. C., downward to the Santee, at Wateree, S. C.

The Catawba is a river of about 207 miles length, and 4,280 square miles of drainage area. It rises in the Blue Ridge Mountains, McDowell County, N. C., near the Western North Carolina Railroad, close to the main divide between the Atlantic and Mississippi basins. It runs first easterly, then southerly through portions of North and South Carolina, and takes the name Wateree at the junction of Wateree Creek, a small tributary entering from the west in the upper part of Fairfield County, S. C., above Camden, S. C.

The Wateree is a continuation of the Catawba, from Camden, S. C., to Wateree, S. C., and unites with the Congaree to form the Santee.

The Santee continues in a southeasterly direction for a distance of 184 miles, and empties into the Atlantic 14 miles south of Winyah Bay. A State canal connects with the Santee at Ferguson, S. C., and runs into the headwaters of the Cooper River at Monks Corner, S. C., thus affording navigation inland from the Santee River to the Charleston (S. C.) Bay.

The surface of the Catawba River from the State line to Camden, S. C., has a descent of 325 feet in 75 miles, or an average of 4.5 feet per mile. At Great Falls, Catawba Canal to Rocky Mount, the amount of descent is 178 feet in 8 miles, of which 50 feet covers one-fourth of a mile. At the Wateree Canal Shoals, slightly above Camden, the descent is 52 feet in 5 miles. The slope ranges from 175 feet above sea at Camden, S. C., to 7.4 feet above sea at Wateree, S. C., where the Congaree and Wateree rivers empty into the Santee; from Wateree, S. C., to St. Stephens, S. C., the surface slope decreases gradually to 50 feet above sea.

It will thus be seen, judging from the rate of descent, that the Catawba, from its headwaters to Camden, S. C., flows very rapidly, most notably during high water. A portion of the water supply registered in the vicinity of Charlotte, N. C., also feeds the Catawba, through one of its small tributaries. According to rainfall measurements on the Catawba, made at Mount Holly, N. C., near the State line, this stream rises, approximately, 8 to 14 feet at Camden, S. C., for each inch of rainfall recorded at Mount Holly, N. C. The volume of water is considerably augmented by rainfall measurements of 1 inch or more at Camden, S. C.

The rising waters from the upper Catawba reach Camden in two and a half days. Two days usually elapse before the stream begins to recede at this point. The flood waters travel much slower between Camden on the Wateree and St. Stephens on the Santee, and reach the latter place in about four and a half days. Two days more are required for the greatly decreased and advancing wave-crests to reach the sea. As in the case of the Great Pedee, a second rise in the Catawba occasionally overtakes the preceding rise before passing half way through the Santee.

The Catawba at Camden has been known to rise 20 feet in one day; it frequently rises 6 feet in twenty-four hours, and continues at this rate for two and even three days. The rates of increasing or decreasing waters in the Catawba are not so great as those observed on the upper Great Pedee.

The immense width and low elevation of the Santee accounts for the slow progress of its waters seaward. The river overflows at a comparatively low stage, and the water spreads over many miles of territory. Rainfalls at any of the river stations above the Santee must be exceptionally heavy to elevate the stream 1 foot in twenty-four hours at St. Stephens. It rises 1 to 2 inches per day for one week or more, remains stationary for one or two days, and then recedes slowly.

During periods of high water the Congaree, at Columbia, S. C., rises about 8 feet in twenty-four hours. It seldom rises over 15 feet in any one day. It remains at a tolerably low stage the entire year.

The ascent of the Congaree to Columbia, S. C., is very steep, from 74 feet above sea at Wateree, S. C., to 235 feet above sea at Columbia, S. C. In its descent from Columbia, S. C., the water passes over three natural dams at Granby, 2 miles below Columbia. The Congaree is navigable from Wateree to Granby. Between Columbia and Granby the slope of the natural water surface at low stage is made up of a succession of pools and rapids. The total fall from Gervais street bridge to Granby, the present head of navigation, varies with the stage of water as follows: At 1 foot above low water, Gervais street gauge, the fall of water surface in the 2 miles discussed is 8 feet; average slope per mile, 4 feet; maximum slope per mile, 12 feet. At 5 feet above low water on the Gervais street gauge the fall of water surface in the 2 miles discussed is 4 feet; average slope per mile, 2 feet; maximum slope per mile, 2 feet. The rising waters reach Columbia, S. C., from the upper Broad River in two and a half days; in one and a half days this advancing volume meets the Santee River at Wateree. Wave-crests first observed at Coronaca, S. C., on the Saluda, reach the Congaree at Columbia in about one day and a half.

Measurements of rainfall made at Gaffney City, S. C., on the upper Broad River during 1893 and 1894 showed a close relation between the water supply over that locality and the amount which passed by Columbia. Rainfall measurements also made at Greenville, S. C., and Coronaca, S. C., for the same period, on the upper Saluda substantiate these facts.

There are three river-gauge stations within the Santee-Catawba-Congaree River basin, namely: (1) At St. Stephens, S. C., on the Santee; (2) at Camden, S. C., on the Catawba-Wateree; and (3) at Columbia, S. C., on the Congaree-Broad-Saluda.

1. The river gauge is located at St. Stephens, S. C., in the Santee basin. Length of the Santee River from St. Stephens, S. C., to Wateree, S. C., 75 miles; length of the Santee River below St. Stephens, S. C., 97 miles; drainage area of the Santee above St. Stephens, S. C., 12,614 square miles; drainage area of the Santee below St. Stephens, S. C., 2,800 square miles. The river gauge was erected in June, 1888, by the United States Engineer Corps, and was placed in possession of the Weather Bureau in April, 1892. Length of gauge, 20 feet; width, 0.5 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black in feet and tenths, the whole feet being represented by brass figures. Position of gauge: On central stone pier of northeastern railroad bridge. Elevation of zero of gauge above sea level, 420 feet; width of river at St. Stephens, S. C., 425 feet; flood or danger line, 20 feet; river overflows at 10 feet; territory overflows at this gauge reading for 3 miles on each side, both north and south, and for 6 miles below and above St. Stephens. Highest water known, equal to reading on the gauge, 20.2 feet, September 18, 1888; lowest water known, equal to zero reading on the gauge, July 18, 19, 1893.

2. The river-gauge station in the Catawba Basin is located at Camden, S. C. Length of the Catawba River above Camden, 230 miles; length of the Catawba-Wateree below Camden, 270 miles; drainage area of the Catawba above Camden, 7,892 square miles; drainage area of the Catawba-Wateree below Camden, 7,522 square miles. The river gauge was constructed by the United States Engineer Corps in 1888, abandoned in 1890, and placed in the possession of the Weather Bureau in May, 1891. Length of gauge, 36 feet; width, 0.8 foot; thickness, 0.1 foot, fastened to circular iron bridge pier. Gauge painted white; graduations painted black in feet and tenths, the whole feet being represented by brass figures. Position of gauge, on middle railroad bridge pier. Elevation of zero of gauge above sea level, 175 feet; width of river at Camden, S. C., 315 feet; flood or danger line, 24 feet; river overflows at 24 feet; territory overflown at these gauge readings, 1 mile each on both sides. Highest water known, equal to reading on the gauge, 31.5 feet, September, 1886.

3. The river-gauge station in the Congaree Basin is located at Columbia, S. C.

Length of the Congaree River and its tributaries above Columbia, S. C., 210 miles; length of the Congaree River below Columbia, S. C., to Wateree, S. C., 40 miles; drainage area of the Congaree River and its tributaries above Columbia, S. C., 7,987 square miles; drainage area of the Congaree from Columbia, S. C., to Wateree, S. C., 325 square miles. The river gauge was constructed or painted by the United States Engineer Corps in 1887, abandoned in 1890, and placed in possession of the Weather Bureau in May, 1891. Length of gauge, 26 feet; width, 0.6 foot, painted on edge of stone pier; thickness of gauge, 4.5 feet, stone pier. Graduations painted black in feet and tenths. Position of gauge, on the northeast corner of central pier Congaree Toll Bridge. Elevation of zero of river gauge above sea level, 233 feet; width of river at Columbia, S. C., 3,200 feet; flood or danger line, 15 feet; river overflows at 14 feet; territory overflown at this gauge reading, 1 mile below Columbia, S. C. Highest water known at these gauge readings, 24 feet, September, 1888; lowest water known at the gauge readings, 0.4 foot, June 20, 1893.

Navigation at Granby, S. C., on the Congaree River 2 miles below Columbia, S. C., is exceedingly difficult; the slope of the natural water surface is made up of a succession of pools and rapids.

A rise of 4 feet at the Gervais Street Bridge is equivalent to a rise of 8 feet at Granby.

At a 5-foot stage steamers can go up the river to Columbia, but under many difficulties, arising from loose bowlders. When steamers reach the Gervais Street Bridge they are at the lower end of a high-level canal, 100 feet wide and 10 feet deep, which extends for 3 miles along Columbia's water front. The canal was built to develop a very large water power.

The bench marks between the railroad and the river gauge were never properly determined. It is said that a series of surveys over this course were made in 1858, but records thereof could not be found. Prof. Benjamin Sloan, of the South Carolina College, at Columbia, S. C., very kindly ran levels back and forth between these two points for this office, and has determined the elevation of the zero of river gauge above sea by connection with South Carolina and Georgia Railroad bench mark.

THE EDISTO RIVER BASIN.

The greater part of the drainage area of the Edisto River lies in Colleton County, S. C., below Edisto, Barnwell County, S. C., where the South Carolina and Georgia Railroad crosses.

The Edisto is formed by the junction of the North and South forks, which unite in the southern part of Orangeburg County, S. C. The South fork, commonly known as the South Edisto, is the main river, and empties into the St. Helena Sound.

Two industries are carried on upon the extreme ends of the Edisto. Timber and lumber is rafted in great quantities down the Edisto and through the inland connections of the Edisto to Charleston. Cross-ties, shingles, etc., are also shipped down the stream, in flatboats, through the Charleston and Savannah Railroad drawbridge, where steam tugs await them to be towed to Charleston, S. C.

The rice interests on the lower Edisto, at and below the Charleston and Savannah Railroad bridge, have reached immense proportions. The rice planters in this section speak in highest terms of the Weather Bureau, which has been the means of saving them one crop of rice since the establishment of the river gauge at Edisto, S. C., in December, 1893.

From the Edisto Island, South Carolina, to a point near Ridgeville, S. C., on the South Carolina and Georgia Railroad, the river runs through an open and swampy country. There is no habitation on this stream between Jacksonboro, S. C., and Edisto, Barnwell County, S. C.

The eastern side of the drainage area runs northerly from Osborn, S. C., to Holly-hill, S. C.; thence northwesterly to Batesburg, Lexington County, S. C. The western limit of the drainage area runs close to the Edisto River over to Smoaks, S. C.; from here it courses northwestward close to and east of Aiken, S. C.; it then courses northward to Trenton, the southeast portion of Edgefield County, where it ends.

The gauge station within the Edisto basin is located at Edisto, Barnwell County, S. C.

Length of the Edisto River from Guignards Landing to Edisto, Barnwell County, S. C., at the South Carolina and Georgia Railroad bridge, 77 miles; length of the Edisto River from Edisto, S. C., to the Charleston and Savannah Railroad bridge at Jacksonboro, S. C., 144 miles; length of the Edisto River from Jacksonboro, S. C., at the Charleston and Savannah Railroad bridge to the Atlantic, or St. Helena Sound, 39 miles; total drainage area of the Edisto above Edisto, S. C., 1,806 square miles; total drainage area of the Edisto below Edisto, S. C., 1,394 square miles.

The river gauge was erected in December, 1893, and belongs to the Weather Bureau. Length of gauge, 9 feet; width, 0.8 foot; thickness, 0.1 foot. Gauge painted white; graduations painted black, in tenths of feet—the whole feet being represented by brass figures; position of gauge, on south (downstream) side of the South Carolina and Georgia Railroad bridge; elevation of zero of gauge above sea, 127 feet; width of river at Edisto, 360 feet; flood or danger line, 6.5 feet; river overflows at 7 feet. Territory overflown at this gauge reading, for 2 miles or more on each side of the stream. At a gauge reading of 8 feet the water spreads out for 4 miles or more on each side of the stream. Highest water known, equal to a reading on the gauge of 8.5 feet, July, 1889; lowest water known, equal to a reading on the gauge of 0.0 foot, November, 1887.

Unlike other streams, the Edisto does not rise over 1.5 feet in twenty-four hours. Its ranges are exceedingly small, due to its excessive width above and below Edisto, S. C. Below a gauge reading of 4.5 feet it rises tolerably fast; above this gauge reading it will continue rising at the rate of 0.3 to 0.5 foot per day for about four or five days, remain stationary for several days, and then recede very slowly, the rate of decline seldom exceeding 0.2 foot per day for a week or more.

A copious rainfall of about 1 to 2 inches reported from Columbia, S. C., or Augusta, Ga., is often followed by a rise of 0.8 to 1.9 feet at Edisto, S. C., within three to four days. This increasing volume of water reaches Jacksonboro, S. C., 144 miles below Edisto, S. C., within six days. With more frequent and heavier rainfall over the upper drainage area of this stream the rate of increase is slightly greater. Good results have followed the forecasting of river stages on this stream at Jacksonboro, S. C., upon this basis.

Aside from their value as affording the means for predicting rapid rises, the streams in the third or Piedmont region, in the upper part of the State, and lying to the north and west of the second or "Sand Hill region," possess an unlimited supply of water power for milling purposes. This section of the State has a good average rainfall of 52 to 60 inches per annum, over an area of nearly 30,000 square miles of drainage, with a large storage capacity and a continuous flow of water throughout the year. Advantages of this kind are of considerable value to concerns which depend upon water for their motive power. These, coupled with a good climate, together with unlimited resources for building materials of every description, make this section a very desirable locality for cotton and other manufacturing purposes. It is doubtful if any other State in these United States can furnish a more varied supply of water for motive power. South Carolina is second on the list of cotton mills.

The average fall of water in the streams of the Piedmont region within this State is about 6 feet per mile. There is hardly a stream of any size that will not give fairly good results if properly "harnessed in." As yet only the natural heads due to direct cascades or rapids have been developed, being so numerous that it has not been necessary, except in a few cases, to build dams of any considerable height, and in many cases bolting of timber to ledges was all that was required for damming streams. Up to the present time only a few of the large powers have been developed, the majority of those used being small ones, ranging from 1,200 horsepower down. The cotton mills, with few exceptions, are located in this Piedmont region. They were established because water power could be obtained cheaper than steam at the time, and when coal was double the price it is now. Not only is good water obtainable, but also cheap wood fuel as well.

There are three flood periods within the basins of the coast region. The first period occurs during January, February, and March, with wonderful regularity, and is caused by the heavy rain and snowfall over the Piedmont region.

The second period occurs during June and July, when the summer showers produce 3 to 6 inches of rainfall in as many hours. This period is irregular, and occurs about once in every three years.

The third period occurs during the three months of August, September, and October, combined, or floods may occur in any one of these three months, between August 15 and October 15. This flood period is, fortunately, quite irregular, occurring once in every three years.

The floods of this period are more to be dreaded than those occurring at any other time of the year.

The rainfall within this period results from the tropical hurricanes which graze our coast and, at times, travel over the State.

The rainfall varies from 6 to 12 inches in one single day. Very often two-thirds of the rice crop will become ruined from floods in ten hours. Cases like these have been known to occur three years in succession.

Since the thorough reorganization of the river service, in August, 1891, thousands of dollars have been saved to the rice planters, stock breeders, steamboat men, and the lumbermen located on the numerous streams in the eastern section of this State.

CHATTANOOGA, TENN.

By Mr. L. M. Pindell, *Observer*.

The Tennessee river and flood system was first organized and established by the Iron and Coal Manufacturers' Association of Chattanooga in 1880, with Rev. J. W. Bachman as chairman. It was investigated by Lieut. W. E. Wright, Engineer Corps, in 1883, and on his recommendation was turned over to the Signal Service, War Department (now Weather Bureau, United States Department of Agriculture), in the same year. This system embraces the Tennessee, with the following tributaries, viz: Hiwassee, Little Tennessee, French Broad, Holston, Clinch, and Powell. All of these tributaries, except Powell and Little Tennessee, have river stations. The head waters of these tributaries are in the mountains of North Carolina and Virginia, and the Holston, Little Tennessee, and Hiwassee have a rainfall station at their heads. From Chattanooga to the head waters there is a drainage area of 81,600 square miles. The French Broad, Holston, and Clinch rivers are the most important factors in furnishing the Tennessee with her water supply. The Little Tennessee is an important river also, but the rise in this tributary, while of considerable weight of importance, does not affect the main body of the Tennessee River like the Clinch, French Broad, and Holston. The Hiwassee is a very quick and rapid rising tributary; it rises sometimes 10 to 12 feet in one day and falls from 6 to 9 feet the next. If the Tennessee River is high and has begun to fall, and the Hiwassee River begins to rise rapidly, the only effect noticed on the river at Chattanooga is that the falling tendency of the Tennessee is checked, and the rise out of the Hiwassee is hardly noticed. When the Tennessee River is at a moderate stage of about 5 to 8 feet, and heavy rains of 2 to 3 inches falling only over the Hiwassee River, that river will rise rapidly, but only about a 3-foot rise will occur at Chattanooga. Under ordinary conditions—that is, when the ground is fairly moist and does not absorb a very large amount of rain and when the rainfall is general over the entire system, and the rise is about 3.9 feet for every inch at Clinton, 3.6 feet at Knoxville, and 4.9 feet at Chattanooga. If the river is at about 5 feet at Chattanooga, and a general rain falls over the system, the first inch will cause a rise of about 7 feet, the next inch about 5 feet, and, as the river reaches the 25-foot mark, the rise is about 4 feet to an inch. After it passes the 33-foot mark, or danger line, the rise is less, owing to the backwater and the lowlands to be flooded. At a 40-foot stage the average rise is 2.5 feet to every inch of rain. This is when the rainfall is general and steady; but when the rainfall is exceedingly heavy, especially when the river is about 20 feet, the average rise is about 4 feet to every inch of rain at Chattanooga. During the past two years it has been frequently noticed that a general rain of from 1 to 1¼ inches makes a very little change in the rivers and tributaries. This is especially so during the summer and fall months, and the only solution that can be given for it is that the ground absorbed a very large portion of the rainfall. It has also been noticed, not only by the observer in charge, but by the river men, that the river has fallen faster than in previous years after a rise, and 0.50 to 1 inch of rainfall does not have much weight in checking its falling tendency. This fact has caused the river men much worry, as it has destroyed all their calculations, and caused trouble in navigating the river during low or moderately low water. It has been noticed that heavy rain falling over the tributaries on the south side of the Tennessee River causes only a slight rise at Chattanooga, but when the heavy rain falls over the northern half, or entire system, the rise is greater or more rapid than in former years, and it is the opinion of all interested that the cause is directly attributable to the clearing up of the country and forest, leaving large fields of exposed lands, from which the water runs into the channel of the river without any material obstruction. When the river reaches 36.5 feet at Chattanooga the people in the lowlands begin to move. At 43-foot stage the river backs up Chattanooga Creek, over the commons near Rouh's cotton mill, and covers the Government road for nearly 300 feet to a depth of 2 feet; it crosses William and Long streets, and the blocks from Montgomery avenue, between Williams and Long, are covered to a depth of 2 to 3 feet; covers Cowart street at one point, and reaches lower floor of most of the houses; Boyce street is covered to a depth of 2 to 3 feet, and lower end of Water street is under water. The river extends one-third of a mile from river banks in Hill City, at 42 feet. When the river is 34 feet at Loudon the lower portion of the town is 20 feet under water. Thirty-foot stage at Chattanooga covers the Chattanooga Island near the river gauge. A 40-foot stage puts the Chattanooga Creek on the floor of the Whiteside Street Bridge. The river begins to run over the railroad track in front of the Loomis Hart mill at 36.9 feet. The Loomis Hart brick warehouse is surrounded by water at a 38-foot stage. Water flows over Montgomery avenue at Standard Oil Company's place at 41.3-foot stage. At a 51.6-foot stage water is over Ninth street in front of Read House. During the past summer and the drought several local storms have occurred, with heavy rainfall over some of the tributaries, which have caused sudden and expected rises in the river at this point (Chattanooga). It appeared, from the muddy condition of the water, that the rain fell so heavily that it all ran off into the river, and the ground absorbed very little. The logmen watch the river and rainfalls very closely, and when heavy rains occur, enough to cause a good rise of 10 to 15 feet, telegraph their agents on the head waters, and have their rafts floated down at once. The inclosed table, No. 1, shows the average rise for every inch of rainfall at each station in the Tennessee river and flood system during each freshet, from 1880 to 1893, inclusive, and has been used to great advantage by the observer in charge in making estimates of rises in the river up to 30 feet. Table No. 2 shows the error in computing rises from amount of rainfall by use of the mean average rise per inch of rain. The table is only given to show how great an error can be made by depending upon the amount of rainfall entirely, without considering the condition of the ground and the general character of the rainfall, whether it is uniform, or comparatively so, over the system, or not. It has been proven, by tests and observations by the City Water Company, that between 20 and 30 feet during a rise the river is muddier and contains more quicksand, dirt, leaves, and other obstructions than when it is higher, and this sediment, mud, etc., extends from the top to the bottom, as proven by the filters of the water company; they have become clogged up and would not work, and the superintendent, Mr. C. D. Barstow, has informed me that it is astonishing to see the amount of quicksand and leaves taken from the filters and around the suction valve after the river falls. The discharge of the river when rising, at 25 feet, with a cross section of 36.648 square feet, is 156,187.264 cubic feet per second, and when falling, at the same height, viz, 25 feet, the discharge is 151,659.945 cubic feet per second. These measurements were made from the Hamilton County Bridge, on May 5 and 8, 1893, by L. M. Pindell, observer Weather Bureau.

I.—*Table showing average rise for every inch of rainfall at each station during each freshet from 1880 to 1893, inclusive.*

Date.	Chattanooga.	Rockwood.	Kingston.	Charleston.	Loudon.	Clinton.	Knoxville.	Strawberry Plains.	Leadville.
	Ft. In.	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*
March, 1880	2 5	....	....	....	....	....	....	....	....
January, 1882	3 0	....	....	....	....	....	....	....	....
January, 1883	4 6	....	....	....	....	....	....	....	....
February, 1884	4 7	....	3 4	4 1	2 5	2 3	2 3	....	3 8
March and April, 1886	3 9	....	3 9	2 7	3 3	3 9	3 3	3 5	3 6
March, 1884	7 6	4 8	5 2	5 1	4 7	4 4	3 8	....	4 7
February, 1891	3 6	3 3	4 0	4 8	5 2	4 3	5 6	2 9	....
March, 1891	5 1	3 1	2 8	3 3	2 8	2 9	2 4	1 4	....
January, 1892	5 9	4 1	4 9	4 5	4 8	4 7	6 6	3 9	....
April, 1892	5 2	2 9	4 0	2 8	2 0	3 8	2 7	2 2	....
February, 1893	4 5	3 0	3 2	3 0	2 6	4 2	2 3	2 8	....
Mean average	4 9	3 6	3 9	3 8	3 6	3 9	3 6	2 8	4 0

II.—*Table showing the error in computing rises from amount of rainfall by use of the mean average rise per inch of rain, for every freshet that has occurred since 1884.*

Date.	Chattanooga.	Rockwood.	Kingston.	Charleston.	Loudon.	Clinton.	Knoxville.	Strawberry Plains.	Leadville.
	Ft. In.	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*	*Ft. In.*
February, 1884	+ 1 2	....	+2 8	− 1 3	+ 5 8	+8 4	+5 2	....	+0 0
March, 1884	−12 2	−6 2	−6 2	− 6 2	− 4 9	−5 2	−3 0	−0 8	−1 5
April, 1886	+11 2	....	−0 2	+11 7	+ 2 3	+2 1	+2 8	+3 4	+1 9
February and March, 1890	−13 9	−3 8	−0 2	− 2 6	− 3 7	−3 2	−1 0	2 9	....
February, 1891	+ 8 8	+1 6	−0 4	− 3 6	− 4 9	−1 5	−6 0	−0 6	....
March, 1891	− 1 0	+3 1	+6 3	+ 2 5	+ 3 9	+5 8	+5 5	+5 6	....
January, 1892	− 4 9	−2 2	−4 1	− 3 9	− 5 5	−2 9	−9 1	−3 5	....
April, 1892	− 1 8	+3 3	−0 5	+ 6 3	+10 0	+0 5	+4 1	+2 6	....
February, 1893	2 7	+3 4	+4 0	+ 3 5	+ 5 8	−2 1	+7 9	+0 3	....
Average error	6 4	3 4	2 7	4 5	5 2	3 1	4 8	2 7	....

DAVENPORT, IOWA.

By Mr. F. J. Walz, *Observer.*

The first tributary of any consequence entering the Mississippi River is the Minnesota, which enters at Fort Snelling, about 6 miles above St. Paul. This river has a drainage area of 12,119 square miles.

From St. Paul to Prescott, Minn., a distance of 30 miles, the Mississippi River is rather sluggish, with easy current and high banks. The river has been much improved for navigation within the past few years by the putting in of numerous wing dams and cutting off sloughs. There is from 3¼ to 4 feet of water in channel at lowest water stage.

The St. Croix River, with a drainage area of 7,146 square miles, enters the Mississippi at Prescott from the west. From this point to Lake Pepin the river runs in a sluggish current, but with very good navigation and much improved, through a valley of from 2 to 4½ miles wide, keeping well to the east side of the valley. About 6 miles above Lake Pepin the river crosses the valley and spreads out through a number of channels, forming numerous sloughs and small lakes.

Lake Pepin is a lake formed in the Mississippi River, and is about 20 miles long and from 2 to 3 miles wide and varies in depth from 20 to 90 feet. It contains no current.

At Reads Landing, just below Lake Pepin, the Chippewa River, with a drainage area of 9,708 square miles, enters the Mississippi. From this point to where the Wisconsin enters, a distance of 151 miles, the Mississippi runs through a sandy valley of some 2 miles in width and high, picturesque bluffs, with a moderate current, winding about and crossing from side to side of this valley, forming a very crooked stream, with alluvial banks and many islands and sand bars.

In this section is the most obstructed part of the river, though it has been considerably improved, and the greater part now furnishes good navigation, and a 4-foot depth is maintained in channel at low-water stage. The Chippewa carries down from Wisconsin much sand and deposits it over this section, which is the cause of a great deal of trouble to navigation and improvement. A large part of the river business begins from the Chippewa, as immense log booms are constructed in that vicinity from which rafts are made up, and out of which springs a great portion of the upper river traffic and industries.

The Black River, with a drainage area of 4,601 square miles, enters at La Crosse, Wis., 72 miles from the Chippewa. From this point to the Wisconsin River the Mississippi is a very sluggish stream and covers almost the whole valley, which is from 2 to 4 miles wide. This section is now considered the most troublesome and hardest for navigation, though it has been much improved by the cutting off of a number of the sloughs, thus confining the water more to the main channel.

From the Wisconsin to the Rock Island Rapids the Mississippi continues with gentle current, crossing and recrossing the valley, which narrows to about 1 to 1½ miles in width, to the Galena, a distance of 70 miles, and then widens out to 4 to 5 miles in width.

Over the Rock Island Rapids, which extend from Le Claire, Iowa, to Davenport, Iowa, a distance of 16 miles, the Mississippi narrows to about three-fourths of a mile in width, and has a swift current, running from 6 to 7 miles per hour. In this distance there are numerous chains of rocks, which, in connection with the swift current, makes navigation dangerous, and necessitates the employment of special pilots for the rapids. These rapids have been much improved for navigation by cutting channels through the rock chains and by a system of wing dams put in to distribute the fall and throw the water into the channels. By the extension of these improvements navigation is being made safer each year and a 4-foot depth maintained at low-water stage.

From the rapids to Muscatine the river widens out and becomes a shallow stream with slack current. Navigation is troublesome in some places during low water, but is being improved. The river valley varies from 1½ to 2 miles in width between the bluffs.

Rock River, with a drainage area of 9,692 square miles, enters the Mississippi 1 mile below Davenport.

Storage reservoirs.—Several storage reservoirs have been constructed at the head waters of the Mississippi River, the principal being at Pokegema Falls. The low-water volume of the Mississippi at Pokegema Falls varies from 500 to 1,000 cubic feet per second, depending on the meteorological conditions. The increment of the volume due to the reservoir water is felt at St. Paul in from seven to ten days, depending upon the stage and current at the time, and causes a rise in the stage of the water at St. Paul of from 0.7 to 1.2 feet, which is maintained. This rise, however, is scarcely appreciable below Lake Pepin.

Commerce and navigation.—The most important business carried on in connection with the navigation of the Upper Mississippi River and its principal tributaries is the lumber trade. Along the river are some 60 large sawmills, which manufacture over 2,000,000,000 feet, B. M., of lumber, and 750,000,000 shingles and lath, the larger part of which is carried for greater or less distance on the Mississippi River, either as logs or lumber.

The average yearly tonnage of the Upper Mississippi River for the past eight years was 3,550,000 tons, and 150,000 passengers, not including those of ferry and excursion boats.

I.—*Drainage area of the Upper Mississippi River at its principal tributaries to the mouth of the Rock River.*

	Square miles.		Square miles.
1. Area above St. Paul	19, 903	9. Upper Iowa	1, 376
2. Minnesota River	12, 119	10. Yellow	652
3. St. Croix	7, 146	11. Wisconsin	12, 867
4. Cannon	1, 690	12. Turkey River	1, 589
5. Chippewa	9, 708	13. Maquoketa River	2, 209
6. Zumbro	1, 604	14. Galena River	1, 895
7. Black	4, 601	15. Wapsipinicon River	2, 957
8. Root	1, 823	16. Rock River	9, 692

II.—The total drainage area of the Mississippi River from Rock River northward, including all creeks and small rivers, is 93,000 square miles.

	Distance from St. Paul.	Distance apart.	Difference in elevation (above sea level).	
			Standard high water.	Standard low water.
	Miles.	*Miles.*	*Feet.*	*Feet.*
Red Wing, Minn	52	22		14. 37
Prescott, Minn	30	30		15. 25
Reads Landing, Minn	84	32	1. 35	. 85
Winona, Minn	125	41	22. 06	24. 30
La Crosse, Wis	156	81	13. 55	12. 58
McGregor, Iowa	231	75		22. 31
Dubuque, Iowa	290	59	15. 93	19. 98
Sabula, Iowa	337	47	15. 93	14. 10
Clinton, Iowa	358	21	5. 49	5. 40
Leclaire, Iowa	381	23	10. 03	3. 37
Davenport, Iowa	397	16	15. 93	20. 74
Muscatine, Iowa	426	29	12. 89	11. 09

GAUGE RELATIONS FOR SEVERAL REPORTING STATIONS BETWEEN ST. PAUL AND DAVENPORT, PLATTED WITH TRIAL INTERVALS IN ACCORDANCE WITH THE METHOD OF MR. JAMES A. SEDDON.

Up to the crest on both the rising and falling stages, each point in a flood wave at the upper gauge must have its period, after which the same value of discharge—and hence the true equivalent of its gauge height—would be found at the lower gauge, due allowance being made for intermediate tributary increment, or when the increments from tributaries are immaterial. If, in platting a trial gauge relation, the assumed time interval were less than the true period, or too short, then on the rising stage the lower gauge values taken would not have had time to rise to their true equivalent value, and would be too small in proportion to the rapidity of the rise. In the same way on the falling stage, the lower gauge values would not have fallen enough, and would be too large in proportion to the rapidity of the fall. By the same reasoning, if the trial interval had been too long, the lower gauge values would have been too large on the rising and too small on the falling stages; and if between the trial intervals an interval is found which causes the relation to plat with the rising and falling stages coinciding throughout, or following nearly the same line, it shows that this interval is the true time interval of flood movement between the two gauges.

As this flood (May 15 to June 6, 1894) was a typical one, in that it was almost entirely caused by heavy rains in one or more showers very close together (May 15 to 18) over Minnesota and Wisconsin, the upper drainage area of the Davenport district, and consequently the greater part of the water passed down the river in one continuous flood, thus producing fair gauge relations, I have with care platted it in accordance with the above simple law, believing that a nearly true time interval for the reaches between the reporting stations would be found.

Of course, in applying these time intervals in forecasting river stages, due attention would have to be paid to rainfall distributed over the drainage area, and the increment from intermediate tributaries. The effect of the latter in this instance is plainly shown in the platted relations by their inclination and straightness.

DUBUQUE, IOWA.

By Mr T. W. RUETE, *Observer.*

The Mississippi River for a distance of about 60 miles north of Dubuque, Iowa, is bounded on the Iowa side by the counties of Allamakee, Clayton, and Dubuque; on the Wisconsin side by Crawford and Grant counties. South of Dubuque, on the Illinois side, the river is bounded by the county of Jo Daviess, and on the south Iowa side, by the county of Clinton.

Bluffs from 50 to 150 feet high form the embankments of the river, generally rising almost perpendicularly from the level of the water, appearing like palisades covered with trees and underbrush.

The many creeks and small rivers find their outlet into the Mississippi through ravines which through ages have been cut down to the bases of the bluffs.

These high embankments of the river are a natural protection against floods and the increased volume of water which at times the river pours down from the upper country. As the farming lands are mostly some distance inland from the river, the damage from high water is not so great as might appear, excepting in the immediate vicinity of and at the city of Dubuque, which latter place covers a more exposed flat territory and has been on several occasions visited by disastrous inundations.

The principal smaller and larger rivers tributary to the Mississippi in the counties north of Dubuque are the upper Iowa, in Allamakee County, and the Turkey River, in Clayton County, Iowa. Below Dubuque, in Jo Daviess County, Ill., the Galena empties into the Mississippi, and on the opposite side the Maquoketa, in Jackson County, Iowa, and the Little Maquoketa, just above Dubuque, and on the east side the Wisconsin River, in Crawford County, Wis., and the Grant and Platt rivers, in Grant County, Wis. Besides, these numerous streams and creeks have their tributaries, and in the early spring, after great snowfalls, these waters often assume formidable proportions, and if a season of rains adds to these volumes of water the Mississippi rises and overflows its banks in the bottom lands and great damage is often the result. . The immense pine forests of Wisconsin are generally covered with great depth of snow, which does not melt until late in the spring, often as late as April and May, and as the rain season sets in about that same period it results in floods, which the great river sends down from Minnesota and Wisconsin. Thus while the country above Dubuque is generally protected by the high rocky embankments, in Jo Daviess County, Ill., opposite and below Dubuque, the hills disappear and recede a great distance from the river, leaving a low stretch of land for miles south exposed to floods. Dubuque has experienced several visitations from high water, particularly in the years of 1880, 1881, and 1888, when the entire lower part of the city, with its manufacturing district, sawmills, and lumber yards, has been submerged, causing great damage.

In 1880 the highest water mark was 28.8, and in 1881, 21.2, and in 1888, 21.7.

In late years the authorities have improved the river banks at Dubuque by the use of sand pumps, which take the sands from the bottom of the river and pumps it on land, raising the banks to greater height and forming excellent protection against floods of moderate proportions.

The river has been known to rise to a great height in midsummer when continuous heavy rainfalls swell the smaller waterways into greater proportions, and so increasing the volume of all the tributaries of the Mississippi sufficiently to cause a great rise of water.

Immediately below Dubuque, about 2 miles, is the little Catfish Creek, which originates as a small brook in Dubuque County and flows through quite a large bed with high embankments through a hilly wooded country, emptying into the Mississippi after passing through the village of Rockdale, 10 miles south of Dubuque.

During the night of the 3d of July, 1876, a tremendous thunderstorm visited this city and neighborhood, lasting with unabated fury from July 3, 10 p. m., until the next morning at 4 a. m., during which time an uninterrupted rainfall inundated the entire vicinity.

On this occasion the usually diminutive Catfish Creek had grown into the proportions of a good-sized river, full to its high banks, carrying houses, bridges, barns, and cattle along its surface and drowning 44 people of Rockdale, sweeping away almost the entire little village. This incident shows the effect of great rainfalls upon small bodies of water in this vicinity and the destruction which may be caused thereby.

As the country becomes more populated and settled greater precaution is taken in guarding against these floods, by improving the banks of the rivers and placing buildings or planting crops where there is less danger from flood disasters.

FORT SMITH, ARK.

By Mr. J. J. O'DONNELL, *Observer.*

The rivers and creeks of this vicinity tributary to the Arkansas, for a distance of 141 miles west and 150 miles east of Fort Smith, viz, from Fort Gibson to Dardanelle, Ark., are described below.

West of the Ozark Mountains and on the north side of the Arkansas River are the following streams, distant from Fort Smith: Camp Creek, 8 miles; Sallisaw Creek, 65; Vian River, 80; Illinois River, 100; Greenleaf River, 110; Grand River, 140; Verdigris River, 141. Those creeks (excepting Illinois, Grand, and Verdigris) have their head waters in the Cherokee Nation, varying in width from 50 to 100 feet, with rock-slate and flint bottom. They have a very rapid current, being all known as mountain streams. The Illinois River, with its tributaries, drains part of Washington, Crawford, and Benton counties, Ark. It is 150 feet wide at its mouth, with banks from 20 to 25 feet high. It is not navigable, but logs are rafted on it for a distance of 100 miles from its mouth. The current is rapid—about 8 or 10 miles an hour when half-bank full. It has a rock-slate bottom.

The Grand River, with a gravel bottom, is 500 feet wide at its mouth, with banks 25 feet high; is navigable for 40 miles to the junction of Neosho and Spring rivers. The Neosho, the principal stream, is navigable for 50 miles farther up; the current of the river when flooded, was measured by Signal Service Observer Campbell and Captain Blakely in 1882 to be 12 miles at Fort Gibson, 2 miles from its mouth. This river has its head waters in Kansas, and drains the western parts of McDonald, Newton, and Jasper counties, Mo.

The Verdigris River is in close proximity to the Grand River and is as large, emptying its waters 1 mile westward; banks about 20 feet wide. It is navigable for 12 miles to the falls, where a ledge of rocks about 4 feet high cross the river. Above these falls it is navigable for 5 miles for flat-bottom boats of 3 feet draft.

On south side are the Porteau at Fort Smith, 300 feet wide, rock bottom, west bank 20 feet for 5 miles from its mouth. Crozier Creek, 30 miles west, and Lan Bois, 50 miles west, etc., streams of inconsiderable size, from 40 to 50 feet wide.

The Canadian, 95 miles west, is about 1,000 feet wide, with sandy bottom, banks 22 to 25 feet, is navigable 50 miles to the junction of North and South forks and to Eufaula on North Fork, 8 miles farther. No information can be procured regarding the Cimarron River.

Relative to floods and high water in the Arkansas River, it is claimed that west of Great Bend floods do not materially affect the river at this place. The principal floods come on the north side from the Illinois, Grand, and Verdigris; on the south side, the Porteau and Canadian. It can easily be discovered when the rise comes out of the Canadian, it being very muddy, with a reddish tint, leaving a deposit of mud and clay of from 6 to 20 inches on the wharf and gauge. This remains on the wharf until washed off by rain or a rise from the Porteau or north-side streams.

The Porteau has head waters in Porteau Mountains in Scott County, 50 miles south. When the Porteau has 17 or 18 feet of water, and there are 4 to 6 feet on gauge, it will raise the gauge to 16 feet. When the Canadian is bank full and 6 feet of water on gauge, it will be raised to at least 20 feet. The Grand and Verdigris rivers, together with 17 or 18 feet of water, about equal the Canadian. When the Canadian, with either of the Illinois, Grand, or Verdigris, comes out strong with about 16 or 17 feet, and there is 5 or 6 feet on gauge, the Arkansas bottom lands will overflow for a distance of 100 miles west and east. When all streams come out the water is backed in the Arkansas above Fort Gibson and the bottom lands will be flooded several feet. High water is much more frequent from the Canadian River country than any other section.

East of Fort Smith the principal creeks on north side, distant from Fort Smith, are Lees Creek, 9 miles, 200 feet wide with 10 feet fall in one-quarter mile from its mouth; Frog Bayou, 45 miles, 200 feet wide; Mulberry Creek, 60 miles, 200 feet wide; Piney Creek, 130 miles, 250 feet wide; Illinois Bayou, 140 miles, 250 feet wide. These streams have head waters in Boston Mountains, northwestern Arkansas, and drain a large area of prairie country. Having a considerable fall, they send off large volumes of water very rapidly. There are none of them navigable for any great distance. On south side are Vashgrass Creek, 25 miles, and Shoal Creek, 120 miles, streams similar to those on north side, but not quite as large, being only about 150 feet wide.

HANNIBAL, MO.

By Mr. Wm. A. Munger, of Hannibal, Mo.

I estimate the watershed of the Missouri side as about 100 miles in length by an average of, say, 55 in width, or 5,500 square miles. The chief waterways that carry the water to the Mississippi, beginning on the north, are the Fox, Wyaconda, North and South Fabius, North and South rivers in Marion County, the Salt, and the Cuivre.

On the east side, in Illinois, the watershed extends from opposite Keokuk to the mouth of the Illinois, 100 miles in length by an average of 20 in width, or 2,000 square miles. This gives a total of about 7,500 square miles' watershed between south of Iowa line and the junction of Illinois and Mississippi rivers. The chief portion of the water from the Illinois shed here mentioned enters the Mississippi River at lower portion of this district, owing to the Shy levee. It is my observation that when the Mississippi River is at a fair stage, say, 7 to 10 feet of water, that a stream the capacity of the Des Moines is able after a good rainfall of, say 3 inches, to discharge sufficient water to raise the stage at Hannibal 3 feet.

It is the accepted rule here that at high stage of river a rise travels at the rate of 30 miles in twenty-four hours, or 1¼ miles per hour. We noticed the past season that on June 4 the Keokuk high stage was 11 feet 4 inches, and on the 6th, at Hannibal, it was 12 feet 2 inches, and, as no local rains occurred, this shows a difference in gauge at the two places of 10 inches. This is perhaps owing to the bridge and levee forcing the water into a more confined channel. In no case during the past twenty years have we had extreme high water, 20 feet and over, unless preceded by heavy rains on the upper river above Davenport. If about ten days or two weeks later there are heavy rains in central and southern Iowa, the meeting of flood waters in vicinity of Keokuk never fails to cause trouble here and bring extreme high water; in fact, in no case can I recall a break on our levee but that we considered the water from the Des Moines was the cause of it.

HARRISBURG, PA.

By Mr. Frank Ridgway, *Observer.*

The Susquehanna River rises in the southwest portion of New York State, and, from the head waters to Sunbury, Pa., it is called the North Branch, which has a watershed of about 12,000 square miles. The northern half of Bradford, the whole of Tioga, and nearly the half of Potter County send their waters into the Susquehanna through the Chemung, which has a drainage of 2,518 square miles and empties into the North Branch 2 miles below Athens, in Bradford County. In addition to this, the river receives waters from the southern half of Bradford and northern half of Sullivan counties through its numerous tributaries. These empty into it as it flows through Bradford, Susquehanna, Lackawanna, and Luzerne counties, which contribute their entire drainage to the North Branch. The whole of this enters the Wyoming Valley through a narrow gorge in the mountains 9 miles above Wilkesbarre. As this valley is only 3 miles wide, with high, precipitous mountains on both sides and with an outlet of but 600 feet, which is also embraced by almost perpendicular mountains, its residents, who number about 100,000, are alarmed at the approach of flood seasons, at which times the river has been known to rise 24 feet in as many hours.

In the spring of 1846 the lower portion of Bloomsburg was completely submerged on account of an ice jam near Catawissa, 6 miles south, and it has since been once or twice partially inundated from the same cause. The bed of the North Branch is ample for all the water and ice that ordinarily pass through. Fishing Creek, which rises about 40 miles west of Bloomsburg and discharges into the North Branch 2 miles south of that place, is a wild stream, rising frequently from 13 to 14 feet above low-water mark and carrying away portions of the farms and timber along its banks. The southern side of the North Branch is well protected by mountains from Nanticoke to Danville and the North Branch Canal parallels it on the north side. I have devoted most of my attention to the West Branch, which is the most troublesome stream in the State and causes the most damage. It rises in Cambria County and drains an area about 7,020 square miles, or about one-ninth that of the State. This area lies at an elevation of from 430 to 2,300 feet above sea level, and its population is about 330,000, or 47 per square mile.

The condition of the river for the passage of water is bad. When the West Branch Canal was built, in 1830, dams were built at Sunbury, Lewisburg, Muncy, and Lockhaven; and when the lumber industry first assumed a prosperous magnitude, in 1860, a dam was built at Williamsport. Since then the river has been given over to the lumbermen. A line of boom piers, 7 miles long, was built in the pool of the dam above Williamsport, and others have been constructed in the river at Lockhaven and other points. All of these are more or less of an obstruction to the passage of water. Logs are worked out of the smaller streams by the process known as "splashing," which consists of clearing the streams of all impediments such as fallen timber, jams of driftwood, rocks, etc. In a dam at the head waters a large body of water is impounded, which, when suddenly released, washes the logs out of the stream that ordinarily has not enough of water to float them. This clearing forces the water to the main affluents much more quickly than formerly when the streams contained innumerable natural dams or barriers made of fallen timber, driftwood, etc. These retarded the flow of the water to a great extent, so that the work done by the lumbermen has had the effect of accelerating the current at the head waters and retarding it in the main river. In order to improve present conditions the reverse of this should be done.

The condition of the watershed at present is such as to cause alarm. The ice in the river passed out below Williamsport during the thaw early in January, but ice is gorged farther north at Linden and the cold weather has closed the river again tighter than before. The ground throughout the entire watershed of the Susquehanna is covered by from 1 to 3 feet of snow, and a sudden thaw is likely to produce a serious flood.

The accompanying profile (fig. 1) shows the fall of the river between the head waters and Havre de Grace, a study of which shows conclusively why the range between high and low water is greater in the vicinity of Williamsport than at any other point above or below. The rate of fall of streams above Lockhaven is from 5 to 50 feet per mile, while from Lockhaven to Williamsport it is 1.59 feet per mile; from Williamsport to Sunbury, 1.67 feet per mile; thence to Harrisburg, 2.10 feet per mile; and from Harrisburg to Havre de Grace, 4.83 feet per mile. It will be seen that the fall between Lockhaven and Williamsport is the least of any, and as this is the stretch of river where the principal torrential streams debouch into the main valley, the water is piled up faster than the river can carry it away and it overflows its banks before it can find other outlets.

Table I, presented herewith, gives to each basin the approximate amount of forest, tilled land, and land that has been cut over and has remained unimproved. Absolute accuracy is not claimed for it, as no reliable data are at hand from which to compile it, but it is as accurate as can be made without any actual survey. It will be observed that only about one-fourth of this large area remains in forest, and to such a pronounced change from the original conditions the frequency and extent of floods must, in a great measure, be attributed.

With a proper system of forest conservation we should have no difficulty in maintaining fully one-half of this area in forest; and until a larger area is maintained, and something is done to check the rapid destruction of what yet remains, more extensive floods than those we have ever had may be expected.

Tables II and III show the percentage of whole area above Muncy and above Williamsport. Ninety-three per cent of the whole area is above Muncy. Below that point the basin narrows, and as the capacity of the channel becomes greater the range between high and low water is not so great.

Table IV contains a list of the floods on the river, compiled from the most reliable data obtainable. The great flood in the West Branch and main river was that of June 1, 1889, which reached 33 feet at Williamsport, about 35 feet at Muncy, gradually decreased to 24 feet at Sunbury, rose to 27 feet 1 inch at Harrisburg (this increase coming from the Juniata at Clarks Ferry), reached 29 feet at Lockhaven, and 18 feet at Clearfield. The flood of 1894 averaged from 2 to 3 feet less than that of 1889. The flood of 1884 was greater on the North Branch than on the West Branch. It would appear from this list that the floods on the West Branch have been increased in magnitude, but this is not the case. On the main river between the mouth of the Juniata and Sunbury the greatest floods were those of 1786 and 1846. The floods of 1889 reached about the same height on the West Branch, and that of 1894 was about 2 feet less, but were probably not so high as those of 1786 and 1846.

The greater floods can be accounted for from the fact that the maximum flow of the North and West branches rarely arrive simultaneously at their junction at Sunbury. In fact, the West Branch was so much higher in 1889 than the North Branch

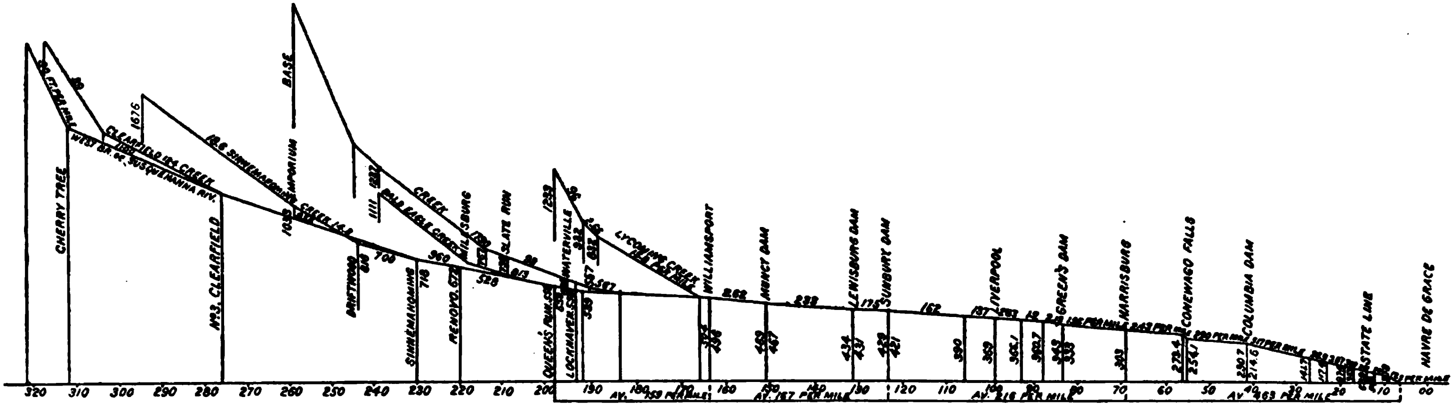


FIG. 1.—OUTLINES SHOWING THE FALL OF THE WEST BRANCH OF THE SUSQUEHANNA, FROM CHERRYTREE TO CHESAPEAKE BAY.

that logs and driftwood from the West Branch floated several miles up the North Branch. A flood on the river below Sunbury does not, therefore, become serious unless the path of the storm is such that the flooded waters from both branches reach Sunbury at the same time.

The waters of the Juniata and West Branch, however, are more apt to arrive at Clarks Ferry at the same time. This conjunction caused the trouble in 1889. It is rare that the Juniata waters do not arrive at the Susquehanna and Clarks Ferry and subside before either the North or West Branch waters arrive. The damage done by the Juniata is confined to its own banks. It has a drainage of 3,223 square miles.

A study of the list of floods seems to dispose of one conjecture that has been current since our last two floods. Many people have held that a flood of any magnitude has been unusual in the past during a season when trees were in foliage, and they have attributed the present changed conditions to the destruction of the forests. The records of floods, however, show that they have been distributed throughout all seasons of the year, and it is not likely that the destruction of the forests has had any effect on the time of year when floods may be expected, but the effect of this denudation is to increase the height of floods when they do occur. This theory is more plausible when it is considered that most of the timber in this watershed was not of deciduous nature. To obtain some indication of the height of water to expect at Williamsport, the height of water reported at Clearfield and at Harrisburg has been doubled. It depends entirely upon the difference in time between the arrival of the high water from the North and West branches at Sunbury and from the Juniata at Clarks Ferry. This method is crude, and is correct only when the amount of rainfall and other conditions are the same throughout the watersheds.

In order properly to predict floods observers should be located in each basin of the watersheds, gauges should be placed at a number of places on the river between Sunbury, at the head waters, and on each of the main affluents. Floods should be predicted very closely from the reports of these observers. To cover the territories properly observers should be located at Sunbury, Lewisburg, Williamsport, Jersey Shore, Lockhaven, Renovo, Keating, Karthaus, and Clearfield. On the main river they should be placed at Hughesville; on the Muncy Creek, at Logan Valley and Ralston; on Lycoming Creek, at Waterville and Slate Run; on Pine Creek, at Driftwood and Emporium; on Bennets branch of the Sinnamahoning, and at Howard and Milesburg, on the Baldeagle. Accurate telephone and telegraphic communication would be an essential feature of this system.

In the flood of 1889 the maximum flood occurred at Williamsport fifteen to sixteen hours after the cessation of the rain. In the flood of 1894 the rain was practically continuous for two or three days before and after the flood, although the heaviest rain was the day before. The maximum flood occurs at Williamsport from eight to twenty-four hours after it occurs in Clearfield; at Sunbury about sixteen hours after Williamsport, and at Harrisburg from six to eight hours after Sunbury. It is 112 miles from Williamsport to Clearfield; 40 miles from Williamsport to Sunbury, and 56 miles from Sunbury to Harrisburg.

The velocity of the river being from 6 to 10 miles per hour, it will be seen that the current and the maximum flood move at about the same rate. From Clearfield and Williamsport to Sunbury the currents move very much faster than the maximum; in fact, during the last two floods the water remained at a maximum from three to four hours, then started to fall very slowly.

I. *Table showing the amount of forest in the basins of the West Branch watershed.*

Name of basin.	Forest.		Tilled land.		Land cut over.		Total.
	Square miles.	Per cent.	Square miles.	Per cent.	Square miles.	Per cent.	
Clearfield	225	15	600	40	675	45	1,500
Sinnamahoning	303	30	150	15	557	55	1,010
Kettle	168	40	42	10	210	50	420
Baldeagle	212	20	318	30	530	50	1,060
Pine	312	25	375	30	563	45	1,250
Lycoming	80	20	120	30	200	50	400
Nippenose	40	25	56	35	64	40	160
Loyalstock	196	40	122	25	172	35	490
Muncy	72	30	84	35	84	35	240
Chillisquaque	33	15	132	60	55	25	200
Whitedeer	40	15	108	40	122	45	270
Total	1,681	24	2,107	30	3,232	46	7 020

II. *Area above Williamsport, Pa.*

	Square miles.	Per cent.	Percentage of the whole watershed.
Forest	1,340	23	80
Tilled land	1,661	29	79
Land cut over	2,799	48	87
Total	5,800	100	83

III. *Area above Muncy.*

	Square miles.	Per cent.	Percentage of the whole watershed.
Forest	1,608	24	96
Tilled land	1,867	29	88
Land cut over	3,055	47	94
Total	6,580	100	93

IV. *List of floods in the Susquehanna River.*

Date.	Height.	Remarks.
February, 1692	No record	
February 12, 1731	do	
February 17, 1733	do	
January 28, 1737	do	3 feet higher than 1733.
January 28, 1744	do	
January 28, 1753	do	
January 7, 1762	do	
January 7, 1772	do	
May 15, 1784	do	The ice flood (on North Branch).
October 5, 1786	do	Called "pumpkin flood."
October 1, 1787	do	
April 1, 1800	do	
April 23, 1804	do	
November 20, 1810	do	Also called "pumpkin flood."
August, 1814	do	
July 20, 1824	do	Water rose higher than ever remembered by oldest residents.
May 5, 1831	do	
June 28, 1829	do	

IV.—*List of floods in the Susquehanna River*—Continued.

Date.	Height at Williamsport.	Height at Harrisburg.	Remarks.
July 4, 1832	No record	No record	
May 17, 1834	do	do	
February 12, 1837	do	do	
May 13, 1846	do	22.2 feet	Greatest since 1786, on main river; 3 or 4 feet higher than any previous rise.
October 9, 1847	25 feet	No record	
August 19, 1851	No record	do	
February 7, 1853	do	do	
September 28, 1861	25 feet	do	
March 17, 1865	27 feet	24.11 feet	
June 1, 1889	33.5 feet	27.1 feet	
May 21, 1894	31 feet	25.7 feet	

KANSAS CITY, MO.

By Mr. P. Connor, *Local Forecast Official.*

Danger begins at 21 feet. At that stage the river begins to encroach on the west bottoms and Harlem, a small village directly north of this city on the opposite side of the river. A 24-foot stage will submerge Harlem and the west bottoms, and cause an overflow in the packing house, wholesale, and manufacturing districts located in what are known as the west bottoms of the city.

An overflow from the regular spring rise is never anticipated, unless coincident with heavy rains in the territory continuous to the river to the South Dakota line. An overflow is most likely to occur in May, June, or early in July.

An overflow is not looked for in the Kansas River, which empties into the Missouri at this place, from continuous heavy rains, while the Missouri is at a comparatively low stage; but with a high stage in the Missouri an overflow is possible in the Kansas, or "Kaw," as it is commonly known, due to heavy rains in northeast Kansas. An overflow will not occur in Armourdale, Kans., until the water reaches a level corresponding to 26 feet on the Missouri gauge, and the bottoms of Kansas City, Kans., until it reaches 28 feet. This information relating to Armourdale and Kansas City, Kans., has been obtained from the city engineer of the latter place.

The river changes at this place are not of a complex character, but are gradual from day to day, depending upon the supply from head waters, considered in connection with the heavy rains in the territory alluded to.

KEOKUK, IOWA.

By Mr. Fred. Z. Gosewich, *Observer.*

The Des Moines Rapids extend 7 miles north of station, the bottom of solid limestone rock, with reefs rising to surface, channel very crooked, and has a fall of 18 feet in the 7 miles.

The rapids channel is navigable for rafts and steamboats when there is a stage of 4 feet of water in the river gauge at Keokuk. Below that stage navigation is dangerous, and at 3¼ feet the rapids are impassable for any but very light-draft boats.

A steamboat canal, built by the Government and operated by the United States Engineer Corps, extends the entire length of the rapids along the Iowa shore, and consists of two levels with three locks.

The larger part of the river traffic is the rafting of lumber and logs from the northern pineries to market centers along the river. Rafts containing several million feet of lumber each, propelled and steered by attendant steamboats, are run over the rapids when the stage of water will permit, making the run in about two hours.

When the rapids are impassable on account of low water, these rafts and steamboats pass through the canal, and in passing, rafts must be divided into sections, in order to pass through the locks, and recoupled when the entire raft has passed—making from 8 to 12 lockages at each lock. In this manner it requires the greater part of two days for a raft with its attendant steamboat to pass through the canal.

It is, therefore, of great advantage to a captain of a raft steamboat to know the stage of water at Keokuk when starting from a northern point with his raft in tow. He can calculate the time required for his trips, and make his contract accordingly.

During the winter a peculiar effect is produced in the stage of water at Keokuk by the rapids.

During cold nights anchor ice will form in the rocky bottom and reefs in the rapids to such an extent as to form a partial dam, and on the following morning the river gauge at Keokuk will show as much as a 1½-foot fall. During the morning this underice will loosen, and by noon the gauge will resume the reading of the previous evening.

The country subject to damage from floods lies between Warsaw and Quincy, in Illinois, and south of the mouth of the Des Moines, in Clark County, Mo.; is protected by levees of earth, sodded on the river side, and in some places further protected by willows planted between the base of the levee and the usual bank of the river. These levees will bear a stage of water corresponding to 15 in the iron gauge at Keokuk, and at 18 feet there is continual danger of parts breaking. High water running from the north, caused by spring rains and the melting of snow, is not sufficient of itself to cause a dangerous flood. Should such a rise, however, in passing south, meet a flood coming out of Keokuk River the danger line would probably be reached at Keokuk, though a disastrous flood would hardly result unless it met with a further swell from the Des Moines.

The Des Moines River seems to be the most important factor in all floods which have caused any great amount of damage. It enters the Mississippi 2½ miles south of the station. North of its mouth the banks are high bluffs, with only a narrow margin of land between the bluffs and the Mississippi. South lie large tracts of rich iron bottom.

A flood coming from the Des Moines, even when the Mississippi is at an ordinary stage, will back the Mississippi as much as 6 inches at Keokuk. Should a flood coming from the Des Moines find the Mississippi at or near the danger line it has the same effect, swelling the Mississippi until the Mississippi flood overcomes the Des Moines flood, when the Des Moines is backed up in its time, which is usually when the flood reaches its height, and the greatest damage is done.

Floods occur with the spring rains in April and May, and occasionally, though much rarer, in autumn.

No floods occur from the breaking of ice gorge in the spring. The Mississippi and all tributaries flowing into it north of the station having a southerly course, milder weather beginning at the southern extremity of the ice, the ice moves out in divisions, beginning south, other divisions thawing and moving out from above them at intervals of days.

At Keokuk the action of the swift current on the rapids will back up the ice while the river is yet frozen from below, which brings down a vast body of water, raising the river from 6 to 8 feet in a few hours. The force of the body of water coming down breaks up the ice below, and the river falls as quickly as it can, without doing any damage.

KNOXVILLE, TENN.

[From Report of the Chief of Engineers, United States Army, 1893, Appendix D D.]

Knoxville, Tenn., is on the Tennessee River. The width of the river at low water is 1,050 feet.

The drainage area above it is 8,300 square miles.

The distance to Loudon is 56.4 miles; to Chattanooga, 183.7 miles.

The river gauge is on the west end of the third pier on the north side of Marysville County Bridge over the Tennessee River at foot of Gay street. The gauge extends from zero to 30 feet; average depth of water below zero of gauge, about 1.5 feet.

The bench mark is the bottom edge of a hole drilled in the stone of second course above the ground on the pier immediately behind the gauge The bench mark is 8.1 feet above the zero of the gauge. The zero of the gauge is 806.6 feet above sea level. The danger line is at 29 feet.

The extreme high water of 1875 and 1876 was 39 feet on the gauge. The extreme low water of 1871 and 1884 was at the zero of the gauge.

The Tennessee River is formed by the junction of the Holston and French Broad rivers, about 4½ miles above Knoxville, Tenn. It flows southwest 51 miles to the mouth of the Little Tennessee River, its first considerable tributary, receiving in that distance only one tributary (other than creeks), the Little Tennessee River.

From the Little Tennessee River it flows west-northwest to the mouth of the Clinch River, the second large tributary, 84 miles from head, and then turning to the left flows south-southwest to Chattanooga, receiving, 150 miles from head, from the southeast, the Hiwassee River. The total length above Chattanooga is 188 miles.

All these streams that form the Tennessee are similar in kind and not very different in size. They rise in the mountains of Virginia and North Carolina and flow down over the rocky, winding beds to their mouths. They are, except the Holston, navigable at ordinary stages for some distance above their mouths, and the French Broad and Hiwassee have regular steamboat service.

The following are results obtained by Col. D. L. Sublett, assistant engineer, at Chattanooga:

Date.	Stage of water.	Discharge.
	Feet.	*Cubic feet.*
November 13, 1891	3.0	17,550
April 11, 1892	30.0	222,650
Calculated high water of 1867	57.5	740,350
Calculated low water	....	8,000 to 9,000

LITTLE ROCK, ARK.

By Mr. T. H. Clarke, *Local Forecast Official.*

In discussing the flood stages of the Arkansas River at Little Rock, there are but three stations from which to deduce results—Fort Smith, Dardanelle, and Little Rock. The distance from Fort Smith to Dardanelle is 95 miles, and from that point to Little Rock, 80 miles.

The chief tributaries on the north side of the river, east of Fort Smith, are Mulberry River, Pine Creek, Illinois Bayou, Point Remove Creek, and Cadron Creek; on the south side, Poteau River, which empties into the Arkansas River, at the west side of Fort Smith, Petite Jean Creek, Fourche La Fave River, and Maumelle Creek.

The streams on the north side of the river are generally mountain streams which fill and run out very rapidly; on the south side of the river the tributaries run through a more level country, and consequently remain at a high stage for a longer period.

In forecasting flood stages, the main features to be observed are as follows: The stage at Fort Smith, the volume of water in the river west of Fort Smith, the rainfall between Fort Smith and Little Rock, the length of time it takes for the tributary streams to empty themselves, the amount of water absorbed by sand bars, and the amount that backs up rivers and creeks and overflows the low lands adjacent to the river at a stage very near the danger line.

From a study of the high-water stages which have occurred from 1890 to the present time, great differences are noted in the rise at Fort Smith as compared with that at Little Rock. In March, 1890, the rise at Little Rock was 89 per cent of that at Fort Smith; in April of the same year it was 103 per cent; in May, 1892, it was 48 per cent, and in June of the same year, 61 per cent; in April and May, 1893, it was 76 per cent, and in March, 1894, 104 per cent. From the above it will be seen that there is a range of 56 per cent between the greatest and least of the comparisons made, but when we eliminate the percentages in 1890 and 1894, on which dates the stages at Fort Smith were below the danger line, we find a range of but 28 per cent between the highest and lowest.

On an examination of the fluctuations between the rise at Fort Smith and that at Little Rock, it is noticed that the higher the stage at Fort Smith the less the relative rise between the two stations, and this is more noticeable when the river is below the danger line at Fort Smith. There is one exception to this rule in the data under discussion—that of April and May, 1893—but this was caused by the unusually heavy rainfall between Fort Smith and Little Rock during the last days of April and 1st of May.

The following tabulated statement will illustrate the point more fully:

Date.	Maximum stage.		Rise at Fort Smith that reached Little Rock.
	Fort Smith.	Little Rock.	
Below danger line:	*Feet.*	*Feet.*	*Per cent.*
March, 1894	17.3	22.6	104
April, 1890	20.9	24.3	103
March, 1890	21.0	22.3	89
Above danger line:			
June, 1892	25.9	25.8	61
April and May, 1893	26.8	25.2	76
May, 1892	30.9	27.9	48

This great falling off in the relative rise of the river between Fort Smith and Little Rock when the stage is above the danger line at Fort Smith, is not so much due to the increased width of the river at a high stage as it is to the overflows and water backing up the rivers and creeks.

At a stage of 22 feet at Fort Smith and 23 feet at Little Rock the river begins to flood low lands between Van Buren and Mulberry, in the vicinity of Dardanelle and Oppelo, and from the mouth of the Fourche La Fave River to just west of Little Rock. Back water ascends the Fourche La Fave and Maumelle to a considerable distance. As shown by the stages at Fort Smith, Dardanelle, and Little Rock, the greatest escape of water from the river is between Dardanelle and Little Rock.

The crest of a freshet wave takes about two days to reach Little Rock from Fort Smith; the average is slightly less than that, depending on the amount of rainfall between the two stations—the less the rainfall the slower the movement of the wave.

At ordinary stages and up to about 21 feet at Fort Smith, Little Rock will receive about an equal rise with Fort Smith; from 21 to 26 feet at Fort Smith, Little Rock will receive about 70 per cent of the total rise at Fort Smith, and from 26 to 30 feet at Fort Smith, Little Rock will receive about 50 per cent of the total rise at Fort Smith.

These rules must be modified somewhat according to the rainfall between the two stations; if general and heavy, the percentage of rise must be increased, and if light or local, reduced. There must also be a great reduction in the above percentages when the stage at Fort Smith exceeds 30 feet and that at Little Rock 28 feet.

Nothing is known of river stages from Little Rock to the mouth of the river, but at 22 feet at Little Rock the river begins to overflow from about 12 miles east of Little Rock to the mouth of the river.

MEMPHIS, TENN.

By Mr. Wm. M. Wilson, *Observer.*

THE EFFECT OF THE ST. FRANCIS BASIN ON FLOOD HEIGHTS AT MEMPHIS AND HELENA.

The St. Francis River has its origin in the low land and swamps lying on the west bank of the Mississippi, about 40 miles north of Cairo. Its course is southward through northeastern Arkansas, and empties into the Mississippi about 12 miles north of Helena. This river drains a portion of southeastern Missouri and nearly the whole of northeastern Arkansas. The drainage area of this stream and its tributaries is comparatively small, about 8,000 square miles, and, as would be expected from this limited area, the effect on the Mississippi at medium and low water stages is nearly inappreciable; but with the great floods which yearly flow down the valleys of the upper water courses, this river assumes an importance by no means commensurate with its apparent insignificance.

The west bank of the Mississippi River from Commerce, Mo., some 40 miles north of Cairo, to the mouth of the St. Francis, is very low, and at a stage of about 42 feet on the gauge at Cairo the water begins to pass through numerous channels, and rapidly fills the basin of the St. Francis.

There has never been any accurate measurement made of the discharge into this basin at the different heights above the flood plane at Cairo, and the estimates made by various engineers show so wide a difference that they are practically valueless.

The basin of the St. Francis is filled with thick undergrowth, canebrakes, and forests, which increase the friction and materially retard the current of that stream; so that the flood wave in the St. Francis is several days behind that of the Mississippi. Again, the basin, being limited in capacity, must of necessity fill before the flood wave can begin its progress, which is another factor in delaying the effect of the wave in that stream.

In order to show the effect of the St. Francis Basin on the flood wave at Memphis, investigation has been made of the relation existing between the gauges at Cairo and Memphis for crest waves of 10, 15, 20, 25, 30, 35, 40, 45, and 50 feet. For this comparison a mean of all waves passing Cairo within 1 foot of the above stages, and the mean of the crest of the same waves when reaching Memphis has been obtained. These data are as follows:

Cairo.	Memphis.	Difference.	Increase of ratio.
9.9	6.3	3.6	....
15.2	10.1	5.1	1.5
20.1	14.3	5.8	0.7
25.0	19.0	6.0	0.2
30.2	23.0	7.2	1.2
35.0	26.7	8.3	1.1
39.9	30.6	9.3	1.0
45.2	33.7	11.5	2.2
50.2	35.0	15.2	3.7

The above means can be plotted as a straight line up to the 40-foot stage at Cairo (see chart 1), which shows that a uniform relation exists at all stages below the flood line. When, however, a stage of 40 feet is reached at Cairo, the previously existing relation entirely disappears, and instead of a straight line, we have a curve which apparently sustains a very indefinite relation to the Cairo gauge. It is to be noted in the above table that the greatest increase in the ratio between the gauges below 40 feet is 1.5 feet, while the mean increase up to the 40-foot stage is 1 foot. From 40 to 45 feet the actual increase of ratio becomes 2.2 feet, which clearly shows that there is a decided falling off in the Memphis reading as compared with the stage to be expected from the Cairo gauge. If we apply the average increase of ratio existing below 40 feet and which is bound to be 1 foot to the 45-foot stage at Cairo, the

Memphis gauge would read 34.9 feet instead of 33.7 feet. It is further noted that the increase of ratio from 45 to 50 feet is 3.7 feet. By applying the mean ratio of increase to the 45 and 50 foot stages, the reading at Memphis for a stage of 50 feet at Cairo becomes 38.9 feet instead of 35 feet. These values charted strengthens the curve and makes the line thus obtained coincide with the line of mean relative readings below 40 feet. The difference between the height thus found, 38.9 feet, and the actual reading obtained from a 50-foot rise at Cairo is considered to approximate very closely the effect of the St. Francis Basin in reducing flood heights at Memphis.

If the St. Francis Basin should be leveed and the relation which has been found to exist between the Memphis and Cairo gauges below 40 feet should be continuous above that plane, the river at Memphis for a 50-foot stage at Cairo would rise about 4 feet above the present maximum flood plane.

In order to show the effect of a flood wave from the St. Francis on the Mississippi River when returning to that stream the mean gauge relation between Memphis and Helena for flood waves which passed Cairo at 10, 15, 20, 25 feet, etc., has been obtained. These relations can also be platted as a straight line up to a stage which corresponds to 40 feet at Cairo, when, as before, the relation disappears. Instead, however, of the Helena gauge showing a lower relative reading than Memphis, as is the case with Memphis when compared with the Cairo gauge, exactly the reverse is found, the curve indicating a greater relative height at Helena than at Memphis.

By a cursory examination of the Memphis and Helena hydrograph for any flood year it will be plainly indicated that there is some powerful factor operating at Helena not to be accounted for by the Memphis chart. The year 1893 affords a notable example of this fact. (See chart 11.) The crest of the flood wave passed Memphis on May 15 to 17, 1893, at a maximum stage of 35.2 feet. The rise for five days preceeding the 15th was 0.3 foot. At Helena the crest passed on May 25, ten days after the maximum height was reached at Memphis, at a stage of 47.9 feet, and the rise for the five days preceeding was 2.1 feet. Every flood that has remained above the 40-foot stage at Cairo for any considerable time, when charted, exhibits this same abrupt curve. It is also noted that the time of the occurrence of the crest at Helena is several days later than would be the case did the Helena gauge depend entirely on water which had passed Memphis.

If we take into consideration the stage at Wittsburg, on the St. Francis River, this apparent discrepancy in readings is easily explained, and it becomes evident that the flood height at Helena depends more on the stage at Wittsburg than the height to which the wave attains at Memphis.

Notwithstanding the energy expended in filling the basin and the force lost in overcoming the friction caused by undergrowth along its bed, the St. Francis River still retains sufficient "head" to force the reading at Helena more than 2 feet higher than the Memphis stage would indicate.

The effect of the St. Francis Basin upon flood heights at Memphis and Helena may be summed up as follows:

1. This basin acts as a reservoir, receiving a large portion of the water which would otherwise flow down the Mississippi River, and thus lowering the flood crest at Memphis about 4 feet below the point indicated by the rise at Cairo did the same relation exist above 40 feet that is found below that line.
2. The water is again returned to the Mississippi 12 miles above Helena, raising the flood plane at that point about 3 feet higher than would be expected from the maximum stage at Memphis.
3. The filling of the St. Francis Basin and the resistance caused by undergrowth and forests retard the flood wave in that stream so that its effect is felt at Helena after the crest wave in the Mississippi has passed that point.
4. The leveeing of the St. Francis Basin would be to cause the flood wave to pass down the Mississippi River from Cairo to Helena as a whole, both as to volume and time: and it is probable that the guage relations existing between Memphis and

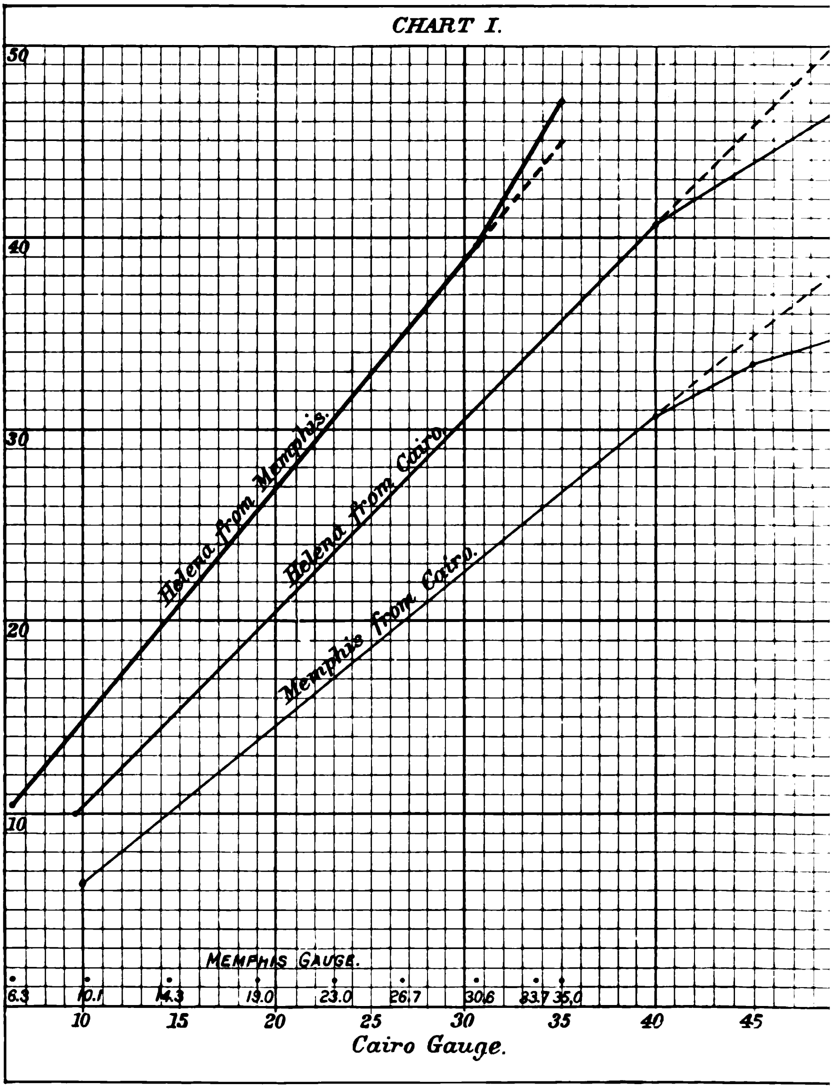
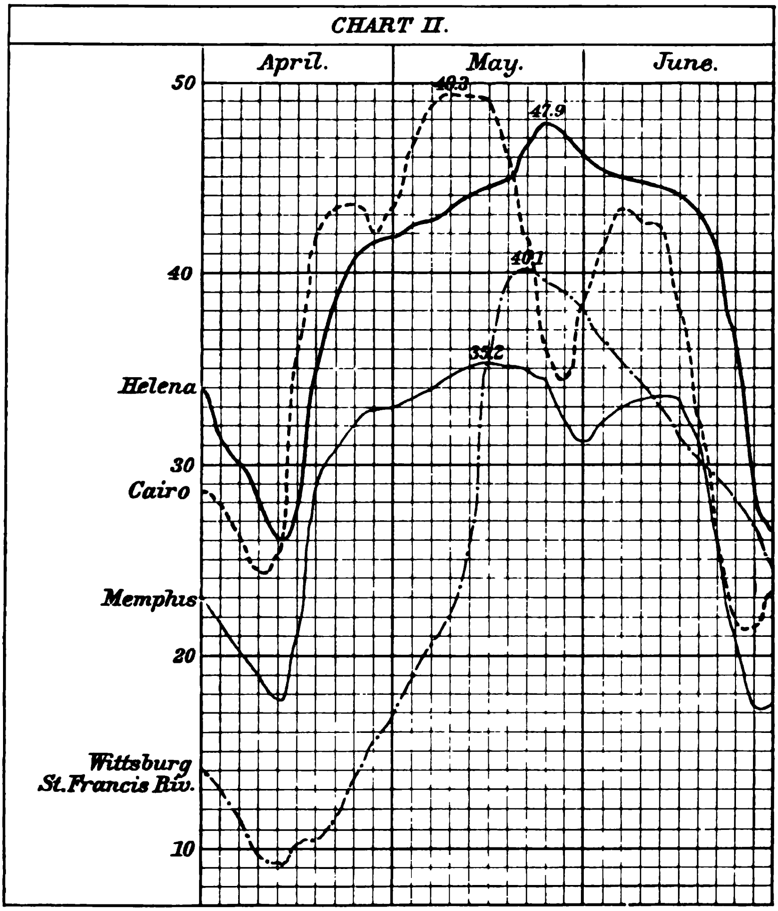


FIG. 2.—GAUGE RELATIONS BETWEEN CAIRO AND

1893



EMPHIS, AND MEMPHIS AND HELENA HYDROGRAPHS.

Cairo and Helena and Cairo below the flood line would tend to be sustained for waves above that height, and the guage reading at Memphis and Helena would approximate the relative height to be expected from a given rise at Cairo.

MONTGOMERY, ALA.

By Mr. F. P. Chaffee, *Local Forecast Official.*

These rivers may be divided into two systems, the northeastern and northwestern. The northeastern system is composed of the Alabama, formed by the junction of the Coosa and Tallapoosa, the Coosa being formed by the junction of the Oostanaula and Etowah rivers of Georgia. This system, down to where the Alabama empties into the Mobile River, drains an area of about 22,000 square miles.

Above Rome the Oostaenaula and Coosawattee rivers are navigable at moderate stages for a distance of 105 miles, and the drainage into these rivers is rapid, as the watersheds are quite abrupt and the soil is mostly of an impermeable character. From Rome to Greensport, Ala , a distance of 162 miles, the Coosa has stable banks and bottom and a normal width of from 300 to 500 feet. From Greensport to Wetumpka, a distance of 142 miles, the character of the river changes; it flows through a rocky country with a succession of shoals and deep pools, varying in length from 1 to 8 miles, with occasional rocky obstructions, which frequently rise above the surface of the water, the water varying in depth from a few inches to several feet. The total fall of the low-water surface from Greensport to Wetumpka is 367 feet. The average low-water width of the river is from 600 to 800 feet. At "The Narrows," about midway of this stretch, it contracts to 100 feet, with a depth of over 85 feet, while the greatest width is 3,700 feet at Butting Ram Shoals, about 38 miles above Wetumpka, where the water is very much dispersed and the river bed an intricate mass of rocks, reefs, and islands.

Observations at Wetumpka, in the fall of 1889, showed a low-water discharge of 5,796 cubic feet per second, which is almost exactly the same as reported for the low-water discharge of the Mississippi River at St. Paul.

The width of the upper Alabama River at low water varies from 500 to 600 feet, and the lower river from 700 to 800 feet, the average slope of the river being about 4 inches to the mile (?). The drainage into this entire system is very abrupt from the west; the divides between the Tombigbee and the Alabama. The watershed from the eastward, while quite abrupt in the northeast portion of the system, flattens out very decidedly in the central and southern portions.

Owing to the impermeable nature of the ground and the incline of the watershed in the northern section, 1 inch of rain in that section would have as much effect upon the middle and lower rivers as would 2 inches of rainfall in same time in the middle section where the ground is more permeable, or 6 inches in same time in the southern section, where the ground is quite absorbent.

Observations of river stages covering the period from 1891 to 1894, inclusive, have been charted at this office, from which the following is deduced:

At moderate stages, less than 25 feet: The rises at Rome, Ga., are felt at Montgomery in about 2 days, with an average rise of 7.3 feet over the Rome stages. From Montgomery to Selma, in 1.6 days, with an average rise of 2.7 feet over the Montgomery stage. Selma to Claiborne, in 2.1 days, but owing to the width of the river and low banks below that point, the rise averages 1.9 less than the rise at Selma.

Stages of 25 feet and over: Rome to Montgomery in 1.7 days, with a rise of 8.9 feet over the Rome stage. Montgomery to Selma, 1.8 days, with a rise of 2.5 feet over the Montgomery stage. Selma to Claiborne, 4.4 days, with the average rise 6.7 feet less than the Selma stage.

It is noticed that the rise at Montgomery depends very much upon the combined inflow from the Tallapoosa and Coosa rivers; fortunately for this section, freshets that occur in the Tallapoosa (as indicated by the Indian meaning the words "Swift Water"), as a rule run into the Alabama and flow off before the full effect of the inflow from the Coosa is felt.

The northwestern, or Tombigbee system, composed of the lower Tombigbee, which is formed by the junction of the upper Tombigbee and the Black Warrior rivers, drains the northeastern portion of Mississippi and nearly all of Alabama west of a line drawn diagonally from southwest to northeast, across the State; in fact, the dividing ridge of the watershed between the two great river systems of this State inclines the same as the general direction of the Appalachian chain of mountains.

As of the northeastern rivers, the same may be said of the watersheds of the upper Tombigbee and the Black Warrior rivers. They are quite abrupt and are composed mostly of rapids above Columbus and Tuscaloosa, are confined to high banks, and the currents are quite swift. The ground surface of the drainage area is divided into the same belts and has very nearly the same characteristics as that of the Alabama and tributaries and is mostly affected by heavy rains in northwestern Alabama and northeastern Mississippi.

The distance from the head waters of the Tombigbee to where that river empties into the Mobile River is about 390 miles. This system drains about 200 square miles.

Average water stages in the Upper Tombigbee reach Demopolis from Columbus, Miss., in 1.8 days, while from Cordova to Tuscaloosa the river distance is nineteen hours and from Tuscaloosa to Demopolis about one day.

At high-water stages it takes a rise at Columbus 1.3 days to travel to Demopolis, with an average rise of 8.4 feet above the Columbus rise.

From Cordova to Tuscaloosa the average time is 0.7 of a day with an average rise of 14.3 feet over the Cordova rise.

Tuscaloosa to Demopolis 3.1 days, with an average rise of 9.2 feet over the Tuscaloosa rise.

It is noticed, however, that in many cases with a freshet coming down the Black Warrior and the upper Tombigbee, the waters from the latter will back up into the Black Warrior and increase the stage at Tuscaloosa, which backwater, after the pressure has been relieved below, will cause a secondary rise at Demopolis about four days later.

Owing to the width of the river and the lowlands below the junction of the Tombigbee and the Alabama, the backwater from either of these rivers has no perceptible effect upon the other.

It is almost impossible to formulate any empirical rule as to the exact effect of rainfalls, reported each twenty-four hours, upon the stage of the rivers of this section.

The intensity and frequency of the rain, as well as the condition of the ground in the watershed, must be considered. For instance, after a prolonged drought, a sudden and heavy rain upon the ground which has been baked to a hard crust will nearly all flow off into the streams, while the same amount falling slowly would be absorbed by the dry earth and go toward replenishing dry springs or be taken up by famishing vegetation and not be felt in the larger rivers for many days.

It is found that the dangerously high waters which have occurred in this section have been during the months from January to May, inclusive, and that the extremely high waters have occurred in January and the latter part of March and during the month of April.

The rains which cause the highest rivers in this section are sudden and excessive, or heavy and prolonged winter and spring rains over northeastern Mississippi, northern Alabama, and northwestern Georgia.

Owing to the extended low-water period usual in these rivers—from June to November, inclusive—regular observations at all river and rainfall stations of this section were discontinued during these months, and special observations telegraphed only when the stages of the rivers or heavy rainfalls made such observations necessary to warn the interests affected.

It is learned from reliable sources that great floods occurred in the rivers of this section in the spring of 1833, and that during the summer months of 1839 (six years later), the water was so low as to permit walking across many portions of the Alabama River. The low waters of the fall months of 1894, said to be lower than at any time since 1839, seems to indicate a period of fifty-five years between extreme low waters.

NASHVILLE, TENN.

By Mr. J. B. Marbury, *Local Forecast Official.*

The Cumberland River rises in the mountains of southeastern Kentucky and flows in semicircular course through the upper and central portions of the State of Tennessee. Its course is extremely crooked for the first 200 miles from its source, after which it is less serpentine. For about 200 miles it passes through a very rough and mountainous country which forms sheds whose drainage is either directly into the Cumberland or brought to it by some of its many tributaries. The upper portion of the river is subject to sudden and decided changes, due both to the topography of the country on either side and to the narrowness of the stream. Near Nashville the river widens and the country becomes less mountainous and rugged, affording less drainage and as a consequence the changes, while still great, are less than at and above Burnside.

The more important of the tributaries of the Cumberland are the Laurem and Rockcastle rivers, 10 and 20 miles above Burnside. These rivers drain a large area of the mountainous country, thus causing sudden and decided rises at Burnside with comparatively small rainfall in that vicinity. At Burnside, it is narrow, not over 100 feet wide at low water. On either side of the river from that point to about 100 miles lower down are high and steep banks From Burnside the river widens gradually to about 400 feet at Carthage at low water and about 700 feet at Nashville. From Nashville to its mouth its width increases.

At Celina, a point about halfway between Carthage and Burnside, the Cumberland receives the water drained from a large section of country by the Obey River. Caney Fork, another important tributary, enters the Cumberland with water drained from a large area just above Carthage. The last tributary of importance reached before arriving at Nashville is the Stone River, which reaches the Cumberland about 10 miles above Nashville.

Changes noted at Burnside generally affect the river at Nashville in from forty-eight to fifty-six hours and are usually modified decidedly by the time this point is reached. A rise or fall at Carthage is noticed here in about twenty-four to thirty-six hours.

The higher the river the less effect a change at the two upper stations have on the river at Nashville. At a 35-foot stage at Nashville, 10 feet change at Burnside will change the readings at Nashville very little unless there have been general rains along the entire course above the last-named point. This fact is due to the widening of river banks and the overflows at various points above this city.

During very high water one peculiarity is noticed here. With the water at or above the 45-foot point it will continue to rise at Nashville for several days after it has fallen at both Carthage and Burnside. Upon investigation it is found that this is due to the fact that the approaches to the two bridges at this point form dams and only allow the water to escape between the piers of the bridge; there is also a third bridge 2 miles below this city whose approaches form a dam fully a mile wide. The combined influence of these forces, I think, is the cause of the rise on the gauge at Nashville mentioned above.

NEW ORLEANS, LA.

By Mr. R. E. Kerkam, *Local Forecast Official.*

A wave of water will occupy about five days in traversing the 366 miles between Vicksburg and New Orleans, and the rate of travel is faster just below Vicksburg, or between Vicksburg and Bayou Sara, than between Bayou Sara and New Orleans. As a general thing it is found that one-third of the Vicksburg rise will equal the New Orleans rise, and that the Bayou Sara rise is somewhere between one-half and one-third the amount of the Vicksburg rise; or, a 35-foot Vicksburg rise will give about 25 feet more water at Bayou Sara and from 10 to 11 feet more at New Orleans. The exact proportion of the flow of Mississippi River water down the Atchafalaya is not yet determined.

Having withstood a stage of 15 feet at New Orleans upon several occasions during late years, it is evident that great improvement has been made in the levee system along the Lower Mississippi; and in view of such facts, the danger line of 13 feet is not, in reality, a danger line any longer. It is only when a stage exceeding 15 feet is anticipated that the levees are closely watched and strengthened wherever necessary, and it is therefore recommended that a new danger line of 15 feet be used for New Orleans. With a stage of 17 feet on the New Orleans gauge the water from the river will commence to flow over the levees, rendering it necessary to erect temporary levees along the city front. Improvements are constantly being made in the levee system of the State, and back or protection levees are placed at many points where, owing to a curving river, the danger of breakage is greater. While scarcely within the province of the Weather Bureau to suggest, yet the disasters of the all-levee system of past years to the agricultural interests render the subject of levees and outlets against all levees of particular interest. The fact remains that our extreme high water of late years in the Lower Mississippi Valley was only a part of that which might have come; that this lower valley has not as yet felt the full effects of the combination of waters from the several central and upper valleys with heavy spring rains; and that it is not unlikely that at some time or other that this condition must be met. A study of the effects of combinations of high waters on the Lower Mississippi Valley would be of great value.

There are so many minor tributaries of the Ouachita River in northeast Louisiana to drain that section that crevasse water from Arkansas is feared by the planters in our northeastern parishes, or breaks in the levees in East Carroll, Madison, Tensas, or Concordia parishes of Louisiana. The marked fluctuations in the Ouachita at Camden are never felt at Monroe, since between Camden and Monroe there is a large tract of country that, when the stage at Monroe passes the 20-foot mark, is overflowed, acting as a reservoir for the flood waters from the upper Ouachita and keeping the stage at Monroe at a more gradual rise or fall. It will be noticed by a reference to chartings of the Ouachita that, whenever the stage at Monroe falls below 20 feet, with a falling river above, the decline is quite rapid to low water. On an average the river at Monroe will show a rise two-thirds as great as at Camden, and within about four days thereafter, if the river at Camden rises some 20 to 30 feet within a week and from a low stage. The rate of travel of a freshet wave between the two points is about 60 miles per day, as near as can be determined.

An approximate rule to follow in forecasting the rises at Shreveport, Coushatta, and Alexandria, on the Red River, is that Shreveport will have from one-half to two-thirds of the rise that occurred at Fulton, Ark., while Fulton will be about one-fifth less than Arthur City, Tex. Coushatta will have about four-fifths of Shreveport's rise, and Alexandria usually has a rise that averages half again as much as at Coushatta. The time consumed to travel the 683 miles between Arthur City and Alexandria is about ten days, and about four days from Alexandria to New Orleans.

PARKERSBURG, W. VA.

By Mr. H. W. Richardson, *Observer.*

The entire State is either mountainous or hilly. The Alleghany and Shenandoah mountains bisect northeast and southwest the eastern arm of the State, the Alleghanies continuing southwest and dividing the State from Virginia to including a portion of the southern border. Parallel to the Alleghanies and running southwest from Pocahontas County is a ridge composed of the Greenbrier Mountains at the northeastern extremity, then follow the Great Flat Top range, finally culminating in what is termed the Dividing Ridge, which follows the entire southern border of McDowell County, W. Va., and the northern borders of Tazewell and Buchanan counties in Virginia. A broad and rather undulating valley covers the intervening territory between the chain of mountains just described and the Alleghanies. The general trend of both chains of mountain systems northeast and southwest through the eastern and southern portions of the State forms the watershed, and the entire district north and west is drained by the Potomac. All the streams of the State have a rapid fall, and consequently run out quickly after flood stage; the rise from normal to flood stage being equally as sudden. The area drained by the Ohio and tributaries at and above Parkersburg is about 34,600 square miles. The difference in altitude between Parkersburg and Oil City, Pa., is about 422 feet; between here and Pittsburg the fall is more gradual, slightly over 130 feet. Parkersburg is distant from the former place nearly 300 miles and from Pittsburg about 182 by river. The Ohio River is increased by the Muskingum at Marietta (12 miles above Parkersburg), by the Little Kanawha at Parkersburg, the Great Kanawha at Point Pleasant (82 miles below), and the Big Sandy at Catlettsburg, Ky. (52 miles below Point Pleasant). The highest water known at Parkersburg was 55 feet on February 9, 1884; the lowest was 0.3 foot on the 10th and 11th of September, 1894; in fact, during the greater portion of July, August, September, and October, 1884, it was unusually low; on forty-five days of the four months mentioned the river reached a stage as low and lower than that of October 30, 1879, 0.66 foot. Navigation is generally open on most of the rivers except in July and August and a part of September, when few if any boats are running on account of low water. Trouble is experienced in the winter months of course on account of ice, but it is the exception rather than the rule that a complete tie-up on this account occurs. The months most favorable for navigation are March, April, May, and June; October, November, and December are also usually favorable, although occasionally there is an exception when during October and November navigation is suspended because of low water. In the section covered by the Ohio and tributaries in West Virginia the average annual precipitation varies from 30 to 35 inches in Ohio, Marshall, Wetzel, Mason, Putnam, and Cabell counties; in the counties of Monongalia, Preston, Tucker, Grant, and Mineral from 40 to 50 inches fall annually; in the intervening districts not mentioned, but tributary and including watershed on eastern and southern borders, the annual precipitation is anywhere from 35 to 45 inches. In the territory drained by the Potomac it varies from 45 to 50 inches in the counties in the region of the Alleghanies and bordering on Maryland to 30 to 35 inches in the extreme arm of the State. The annual snowfall in West Virginia averages in depth about 3 feet over the region covered by the Ohio Valley, the fall then increases gradually to about 6 feet over the territory drained by the Monongahela and the upper Potomac; in the extreme eastern portion of the State drained by the Potomac the average snowfall is about 3 feet. It is very seldom that the Ohio and tributaries in this section are completely closed up by ice. When this occurs, much danger is apprehended on account of the ice gorging and the final break-up. If the snow and ice thaw gradually, no serious consequences ensue, but if the break-up is caused and is accompanied by continual warm weather and copious rains the results are apt to be disastrous. The months most favorable for floods are January and February. Freshets occasionally occur in March, April, May, and September, and a good rise is almost always confidently looked for in June. An examination of the records discloses the fact that in the majority of instances Pittsburg is the main index point as regards an expected flood stage at Parkersburg. Whatever the flood stage at Pittsburg may be, the flood stage at Parkersburg will be about 12 feet higher nearly two days later, the rate of travel of crest being about 92 miles per day between the two points. Of course the flood stage at Parkersburg might be slightly more or less than indicated by the additional 12 feet more than at Pittsburg, depending altogether upon conditions existing as to the distribution of the rainfall, the amount of snow on the ground in the districts drained, the thickness of ice, if any, in the rivers, and the location and extent of ice gorges. Ice is a specially important feature both as to gorges and displacement when in motion. Careful study of previous records and the consideration, combined with a fairly accurate knowledge, of the effects of the conditions mentioned in time reduces such calculations to something like a pure mechanical process. Much depends also as to whether the rivers are running out rapidly below Parkersburg; the Great Kanawha and Big Sandy when running full have a tendency to "back" the water in this vicinity. As a rule, the Muskingum and Little Kanawha run out quickly; when these rivers have a "secondary" rise and run out on top of a flood stage in the Ohio, it almost always follows that Marietta and Parkersburg are visited by more than usual flood. A fall at head waters to Pittsburg and below Davis Island Dam is generally followed by a fall at Parkersburg of from two to two and one-half or nearly three days later, other conditions being equal and the Muskingum and Little Kanawha quiet. The "danger line" at Parkersburg is 38 feet, but this is thought to be too high, as at a height of 38 feet many houses in Riverside, an eastern suburb adjoining the Ohio and but recently added to the city, have to be abandoned; at 37 feet several of these houses are half under water. The river gauge is at the junction of the Little Kanawha with the Ohio, is attached to a pier of the Ohio River Railroad Bridge, and extends to a little more than 40 feet above the zero. There is a United States engineer's gauge on the opposite side of the Ohio at Belpre. River information is valued here by almost all classes of citizens. The interests affected are many and varied. Traffic on the Ohio is mostly in coal and merchandise, although a few boats are equipped with passenger facilities more especially. On the Little Kanawha there are all the other interests combined, together with an immense amount of timber in the shape of logs and ties annually brought out. Frequently millions of feet of timber lie in the upper waters of this river awaiting a rise; as a consequence weather forecasts are watched with the keenest interest by those financially concerned. The Little Kanawha is navigable to Creston, 58 miles above Parkersburg. Transportation is effected almost entirely by boat, there being no railroad through.

The river reports received at Parkersburg are as follows: Monongahela, Morgantown; Alleghany, Oil City, Parkers Landing, Pittsburg; Ohio, Davis Island Dam (from Western Union free), Wheeling, Marietta (telephone free), Point Pleasant, Cincinnati, Cairo; Great Kanawha, Hinton and Charleston; Little Kanawha, Creston and Leachtown, daily, free by telephone, and any other points desired. Importance is attached to all these reports, and the river bulletin has been made an especial feature on the daily weather map.

PORTLAND, OREG.

By Mr. B. S. Pague, *Local Forecast Official.*

THE COLUMBIA AND TRIBUTARY RIVERS EAST OF THE CASCADES.

The Columbia River, with its tributaries, drains that portion of the United States west of the one hundred and thirteenth meridian and north of latitude 42° except a portion of northwestern Washington and southwest Oregon. The greater portion of the eastern half of British Columbia is also drained by the Columbia and its tributaries. The area drained amounts to upward of 350,000 square miles, or about 225,000,000 acres. The main tributaries of the Columbia are the Willamette in western Oregon, the Snake in Idaho, the Kootenai of Montana and British Columbia, and Lake Pend Oreille in northern Idaho.

Station.	Average annual precipitation.	Average for five months (November to March, inclusive).
Helena	14.27	4.46
Spokane	20.08	11.04
Walla Walla	17.94	10.08
Umatilla	9.96	5.67
The Dalles	15.57	11.34
Baker	14.63	8.10
Boise City	14.30	8.07

The above stations cover the country drained and represent very fairly the precipitation to be carried off by the Columbia River. In the second table the average for five months shows approximately the amount of snowfall.

Helena, Mont., lies close to the highest elevation of the Rocky Mountains in that latitude (nearly 47° N.). There the precipitation is partially due to cyclonic areas moving southward on the east side of the Rockies. About 32 per cent of it is in the form of snow, which would make about 4 feet of snow per annum. This represents approximately the amount of snow in the mountains of western Montana to be melted by the warm weather of spring and early summer and emptied into the streams.

Spokane, in northeastern Washington, has the highest precipitation of the stations given above. This is due to its proximity to the western slope of the mountains and the topographical features surrounding it. While the precipitation given for the months likely to have snowfall is about 11.04 inches, it must not be surmised that there is that much snowfall at that point. Spokane has an average of approximately 6 feet of snowfall per annum, and this fairly represents the amount of snowfall in the mountains of northeastern Washington, northern Idaho, and southwestern British Columbia that will be melted in the springtime.

Walla Walla, in the southeastern portion of Washington, represents the great basin of the Columbia with 17.94 inches of precipitation, of which 10.08 inches occur during the months when snow is probable. Owing to peculiar climatic conditions, January is the only month having a mean temperature below the freezing point, viz, 30.6°. January and February are the only months with a mean minimum temperature below 32°. The lowest mean maximum occurs in January, viz, 36.3°; hence it is seen that in the immediate Columbia River basin there is but little chance for any material amount of snowfall to influence the river during flood periods.

Umatilla, in Oregon, and to the west of Walla Walla, has an annual precipitation of 9.96 inches, of which there is a possibility of 5.67 inches in the form of snow. Its climatic conditions being quite similar to those of Walla Walla, there is small snowfall to influence the river. Umatilla represents the eastern slope of the Cascade Mountains, while Walla Walla the eastern side, or more nearly the center, of the valley, between the eastern slope of the Cascades and the western slope of the Rocky Mountains.

The Dalles, Oreg., lies on the immediate eastern side of the Cascades, about 45 miles from their crest (latitude 45° 30′ N.). Here is found an annual precipitation of 15.57 inches, with about 11.34 inches thereof during probable snowfall periods. The climatic conditions here do not differ much from those of Walla Walla, yet the 11.34 inches of snow can be approximately used as the amount of precipitation that occurs on the eastern side of the Cascades for a distance of 45 miles from the summit.

Baker City, Oreg., and Boise City, Idaho, represent very fairly the amount of precipitation that occurs over Oregon, east of the Blue Mountains and over the whole of Idaho.

These stations show about 8 inches of water from probable snowfall; not over one-half this amount is subject to use during the time of probable flood periods, due to the frequent melting of snow during the winter time under the influence of the "Chinook winds." The "Chinook winds" affect the whole country now being discussed, and by frequently melting the snow during the winter months cause the water to run off and reduce the supply for flood purposes.

FLOODS AND THEIR CAUSES.

The Columbia River flows for about 400 miles before it strikes the international boundary line in northeastern Washington, thence 769 miles to the Pacific Ocean. The Columbia enters the United States at an elevation of about 1,305 feet. The Snake River has its source in the vicinity of the Yellowstone National Park, in Wyoming, and is some 900 miles long to Pasco, Wash., where it empties into the Columbia. The elevation of the Snake along its course to where it strikes the boundary line of Oregon is over 2,000 feet, from which point to the Columbia River it falls rapidly. Pasco, Wash., at the mouth of the Snake, has an elevation of 410 feet. From Pasco to the mouth of the Willamette (Portland) the distance is 240 miles, and there is a fall of 400 feet.

The results of the survey of the Columbia River, made about three years ago by the United States Engineer Corps, show at one portion of the river south of the international boundary line, where the observations were made to determine the volume of flow, that at a low stage of water the flow was 50,000 cubic feet per second, and at a high stage of water 300,000 cubic feet per second, the difference between high and low water at that point being 40 feet. The flow of the Snake River at an average height may not exceed by more than one-half the flow of the Columbia at the point observed. The mountains furnishing the snow for the river's supply are the Cascades, Colville Mountains, Chelan range, Cœur d'Alene and Kootenai mountains, Selkirk, and Purcelle ranges, Salmon River Mountains, Blackfoot, Cariboo, Bannock, Port Neuf, Snake River, and Blue mountains. The last named in Oregon, the preceding six in Idaho, the others in Montana, British Columbia, and Washington.

The accumulated snow of winter gives away to the increasing heat of summer, and from this cause high water and sometimes floods result. The best example of flood causes will be found in the high water of 1894, when the Columbia River was higher than ever before known. The amount of precipitation during the winter of 1893–94 was about normal, but the temperature was slightly below the average, which permitted of a great accumulation of snow, which was later rapidly melted during a warm period in the latter part of May.

The flood was the more severe below the mouth of the Snake on account of the snow along the upper Columbia and along the Snake melting at one and the same time. So far as precipitation is concerned, conditions favorable for the occurrence of floods in the Columbia obtain every year; but the floods depend entirely upon the temperature conditions. An early spring or a slowly approaching spring will cause a gradual melting of the snow and no especially high water will result; but a late spring, with a sudden period of warm weather, will surely produce flood conditions.

The following table shows the date of the highest water at Portland, Oreg. (on the Willamette River), each year since 1880, due to the rise in the Columbia River and consequent backwater in the Willamette:

Year.	Highest.	Date.	Year.	Highest.	Date.
	Feet.			*Feet.*	
1880	25.4	June 30 and July 12.	1888	18.2	June 18.
1881	19.7	June 16.	1889	10.0	May 21.
1882	23.2	June 15.	1890	20.1	May 20.
1883	17.9	Do.	1891	14.1	June 7.
1884	20.2	Do.	1892	19.3	June 24.
1885	14.5	June 23.	1893	21.0 22.0	May 22. June 15.
1886	20.0	June 9.	1894	33.0	June 7.
1887	25.7	June 21.			

The above shows that the Columbia River floods occur from May 15 to July 15, with a great number of them before June 20. As noted before, the rise in the river depends upon the rapidity of melting of the snow, and this is due to the temperature. The flood probabilities are determined from the temperature conditions that prevail from about May 15 to June 15.

HISTORY OF THE COLUMBIA RIVER SERVICE.

River gauge readings have been made at Cascade Locks, Oreg., by the United States Engineer Corps since 1880 and are still being carefully made at this date, copies of the records being at the disposal of this Bureau. Readings of the river gauge have been taken for part of each year at The Dalles, Oreg., since 1890. At Umatilla, Oreg., readings were taken from March, 1878, to March, 1887; partial readings only from 1883 to 1887. In 1890 and 1891, readings were taken only during probable flood periods, and from 1892 to October, 1894, daily readings were made. At Pasco, Wash., the Northern Pacific Railroad takes readings and furnishes this office with copies of its records whenever desired. River records made at Riparia, Wash., by the Oregon Railway and Navigation Company (on the Snake River) are also available whenever desired. A record was made in former years at Lewiston, Idaho, but the same appears to have been lost. A brief record for 1892 was made at Ontario, Oreg. A partial record was made by the Union Pacific Railway at Huntington, Oreg., but is not available. Gauges were erected during December, 1894, at Northport, Wash.; Wenatchee, Wash.; Lewiston, Idaho, and Weiser, Idaho.

The gauges at Umatilla and The Dalles, Oreg., were repaired. The river gauges along the Columbia and Snake rivers available for record at this date are at the following places: Northport and Wenatchee, Wash.; Lewiston and Weiser, Idaho; Umatilla and The Dalles, Oreg., and by cooperation with others, Riparia and Pasco, Wash., and Cascade Locks, Oreg.; all of which go to make a complete and satisfactory river service. With a service not nearly so good, this office saved to the merchants of Portland alone, by successful flood warnings issued during June, 1894, the sum of $240,500, of which there is a record, and many thousands of dollars to others of which there was no record kept.

THE WILLAMETTE RIVER.

This is the main tributary of the Columbia west of the Cascades and drains the fertile Willamette Valley. It is some 200 miles from its source in the Cascades and Calapooia Mountains to its mouth, which is 6 miles north of Portland, where it empties into the Columbia River. It has numerous tributaries; there are about 40 streams that feed it during its course. The main river is navigable for about 100 miles from its mouth.

CAUSE OF FLOODS IN THE WILLAMETTE VALLEY.

The main cause of floods in this valley is the complete saturation of the soil by the rains of November and December; the prevailing high humidity prevents evaporation, so that usually all the rain falling after January 1 runs off and into the rivers, the natural drainage canals—the numerous small streams quickly precipitating the fallen rain into the main river, which, being unable to discharge rapidly enough, produces the rapid rise. In 1881 a flood resulted from the very heavy rainfall, which produced its greatest effect about February 7, on which date the river stood 23.8 feet at Portland, having risen 17 feet in six days. The heavy rainfall occurred on the 1st and 2d of February, and amounted to about 4 inches in forty-eight hours. The heaviest rainfall on record at Portland is 10.61 inches in forty hours on December 12–13, 1882. The forty days preceding this excessive precipitation was comparatively dry, hence a large amount thereof was absorbed by the soil; it was, nevertheless, sufficient to cause the river to rise from 6.5 to 18.5 feet in three days.

Save in one single instance the rainfall alone has not caused the river to rise above 18.7 feet, and in this one instance, viz, February 7, 1881, the rapid increase in temperature during the first few days of February caused the snow in the mountains to melt rapidly and in this way materially assisted the rainfall in causing the flood.

The highest water on record produced by the Willamette River alone occurred on February 5, 1890, when the gauge at Portland showed 28.7 feet. Corresponding high water prevailed through the valley, which resulted in doing damage to the extent of $1,000,000. This flood followed the heavy rains that fell from January 22 to February 5, during which period 15.67 inches of rain fell at Portland. Just previous to the commencement of this heavy rainfall about 35.3 inches of snow fell, making a total of 19.2 inches of water at Portland, which went into the river in a short time

The precipitation in the Willamette Valley averages about 75 per cent of that at Portland, so that approximately 12.15 inches of water flowed into the river within two weeks' time, and the result was the great spring freshet of 1890. The following highest waters, with dates each year, resulting from purely local causes in the Willamette Valley, will prove of interest:

Year.	Height.	Date.	Year.	Height.	Date.
	Feet.			*Feet.*	
1880	15.9	January 9.	1888	16.2	February 1.
1881	23.8	February 7.	1889	4.2	January 24.
1882	18.5	December 16.	1890 [1]	28.7	February 5.
1882	14.8	March 4.	1891	6.0	March 28.
1883	16.7	February 2.	1892	12.1	January 5.
1884	12.0	February 25.	1893	18.7	December 4.
1885	15.9	January 9.	1893	8.8	February 14.
1886	17.1	February 4.	1894	16.1	January 23.
1887	15.8	February 1.	1894 [2]	18.0	March 19.

[1] Special reading at 5 p. m., one hundred and twentieth meridian.

[2] During April, 1894, the river was from 11.9 to 17.8 feet. On May 2 it was 17.9. It then fell to 15.2 on May 6, and rose steadily to a maximum of 33 feet on June 7.

HISTORY OF THE RIVER GAUGES ALONG THE WILLAMETTE RIVER.

The river gauge at Portland was first established by the city engineer about 1872. The records previous to 1879 are in his possession. On March 16, 1879, observations of the height of the river were begun and a record kept daily by this Bureau which have been kept up ever since. At Oregon City, 18 miles south of Portland, a gauge has been in use for the past five years by the Willamette Pulp and Paper Company, at whose offices a record has been made, during high water only, of the height of the river. A record is supposed to have been made by the lock company at that place prior to that of the paper company, but no trace of it can be found to-day. At Salem a gauge was erected by this Bureau in 1890 and a partial record has been made since at that point. Gauges were erected at Albany and Eugene by the Weather Bureau in 1878 (November), and since then partial records have been made, principally during the winter months. Excellent river gauges, owned by this Bureau, are now located at Eugene, Albany, Salem, and Portland. Gauge readings can be obtained at any time from Oregon City when desired.

FLOODS AT PORTLAND.

Portland is on the Willamette, the river flowing through the center of this city, and is 6 miles from where the river empties into the great Columbia.

About 18 miles south of Portland are Willamette Falls. At Portland the zero of the river gauge is 4 or 5 feet (surveyors differ) above mean low tide at Astoria, 100 miles west.

When the river at Portland stands at 3 feet above zero, there is a tide of 3 feet shown on the gauge at the time of high tide. The lower docks along the river front are from 15 to 18 feet above the zero of the gauge. The cellars of buildings on Front street (the first street from the river) on the west bank are from 17.5 to 19 feet above the zero mark. Hence the danger point begins at about 15 feet, though damage is not done until 17.5 feet are reached. Portland is subject to freshets of the Willamette River, that occur usually about February 1, and to the backwater incident to the rise in the Columbia, which takes place, as a rule, in June. The Columbia rises and prevents the Willamette from discharging its waters into it, and hence this water is backed up to the falls at Oregon City. About 4 miles south of Portland a rapid rise of the land occurs, and the result is that the backwater flood is confined principally to within 10 miles of the Columbia River.

RALEIGH, N. C.

By C. F. VON HERRMANN, *Observer.*

The western streams of North Carolina are short and very rapid, and no system of river and flood warnings has been established. Predictions of floods could here only be made from the probability for excessive rains, not from river-gauge readings, as the rise of these rivers is too rapid to enable the stages to be telegraphed to the central office in time for the issue of flood warnings.

The rivers in the east, however, have a much longer course, and flow in the eastern district through alluvial formations still being built up by the rivers themselves. Here floods are sufficiently frequent and destructive to make the system of river and flood warnings established by the Weather Bureau of great value to agricultural and other interests in this section of the State.

The average annual precipitation for North Carolina is nearly 4¼ feet. The greater part of this large amount of water finds its way to the sea through thirteen large streams. The drainage areas may be classified into three systems: (1) Areas wholly within the State, or nearly so, whose streams reach the ocean within the coast line of North Carolina; (2) the rivers which enter the Atlantic through South Carolina; (3) the areas west of the crest of the Blue Ridge, whose waters finally enter the Gulf of Mexico through the Mississippi River.

1. To the first system belong the innumerable small streams entering the sounds, which have very little fall, generally less than 1 foot to the mile, and five large rivers, the Chowan, Roanoke, Tar, Neuse, and Cape Fear.

The Roanoke, with its tributary, the Dan, is the longest river of the State, and has its sources in the Blue Ridge. Its total length is 300 miles, and it drains the northern counties from Stokes to Northampton. The total area drained probably exceeds 8,000 square miles. A large volume of water enters it through its Virginia tributary, the Staunton. The fall of the Roanoke from Danbury, in Stokes County, to the point of entrance into Albemarle Sound is 700 feet. The river is navigable as far as Weldon. Extensive farms along the lower course of the Roanoke are in some cases protected from floods by embankments; numerous islands which appear during low water are used for stock.

The largest streams south of the Roanoke are the Tar, Neuse, and Cape Fear. The Tar drains eight counties, and is navigable up to Tarboro. The Neuse, rising in the highlands of Person County, flows southeast into Pamlico Sound at Newbern, where the river is over a mile wide.

The Cape Fear River drains the largest area in the State, over 8,000 square miles. The river rises in the northwest corner of Guilford County, pursues a southeast course, and enters the Atlantic 30 miles below Wilmington. The fall throughout its course is over 500 feet. It is navigable for 150 miles up to Fayetteville. When the river is high a large area of farm land is flooded, and lumber and milling interests at Wilmington are also affected.

2. The chief rivers of the second system which flow through South Carolina are the Yadkin and Catawba. They have very similar courses, rising on the eastern slope of the Blue Ridge, flowing first eastward, and then curving sharply southward. The largest of these rivers, the Yadkin, has a length of 250 miles; its fall to the land is 500 feet, and 700 feet more to Cheraw, S. C. Its drainage area is about 5,000 square miles. The Catawba and Broad are important as the sources of the Santee River of South Carolina.

The six rivers of the third drainage system are the Hiwassee, Big Pigeon, Tennessee, French Broad, Watauga, and New. The last takes an unusual course northward into the Ohio River from the northwest corner of the State. The valleys of these streams are inclosed basins, and the waters pass the western mountain barrier through deep and rugged gorges.

3. Some records of high water previous and subsequent to the establishment of river stations, and some remarks on the rapidity or rise and freezing of the rivers of North Carolina.

There is a tradition that the highest stages of the rivers of North Carolina were reached during the great May freshet of 1771.

Very high stages of the Roanoke River occurred in 1862, when the river reached about 38 feet above low water on June 7. On January 5, 1865, Fayetteville reported as 75 feet above low water, but which recent circumstances indicate could not have exceeded 50 feet on the present gauge.

Other destructive freshets occurred May 10, 1873, and September 25, 1876.

The highest stage of the Roanoke ever reached is said to have occurred in November, 1877. The waters touched the highest points ever reported at Danville, Va., namely, 19 feet, and at Clarksville, Va., 27 feet; and on November 26 the stage at Weldon was 46 feet 8 inches, which has not since been exceeded.

Other floods on the Roanoke occurred July 4, 1886, September 13, 1888, and June 1, July 2, and August 3, 1889.

Coming down to times for which authentic records exist, the following data of interest may be mentioned:

At Mount Holly the Catawba River reached the highest stage, 14 feet, August 3, 1887. The danger line is placed at 20 feet. The lowest is 0.2 foot in June, 1890.

At Weldon the Roanoke River passed the danger line, 27 feet, in February, March, April, May, June, and August, 1891; highest, 35 feet, May 31. In 1892 it exceeded the danger line, January 15 to 23; highest, 33.6 feet, on January 16. In 1893 the highest stage reached was 39 feet, September 16. The lowest river was 0.1 foot, October, 1892.

A remarkable rise of the rivers of eastern North Carolina occurred January 9 to 15, 1895, which was successfully predicted by the Weather Bureau. The Cape Fear River, at Fayetteville, reached the highest stage ever known, namely, 58 feet, on January 12, and rose to within 5 feet of the great flood of November, 1877. Owing to the season of the year, comparatively little damage was done.

The rapidity with which the rivers rise requires the greatest vigilance and promptness in issuing warnings. A rise has occurred at Weldon of as much as 25 feet, and at Fayetteville as much as 30 feet in twenty-four hours, the rivers thus reaching the danger line from relatively low stages within a day.

Ordinarily the waters of North Carolina remain open all the year, except the smaller streams in the western district. During severe winters, such as occurred in 1857, 1886, and 1895, all the rivers freeze and even the sounds, except the central portion of Pamlico Sound, and the lower courses of the streams in the southeast corner of the State. In 1893, for instance, Albemarle Sound, from Elizabeth City to Roanoke Island, was frozen from 8 to 14 inches thick from the 2d to the 28th. Currituck Sound was frozen over nearly the entire month. The Cape Fear, at Fayetteville, was frozen over from the 19th to the 27th; the Neuse, at Newbern, 18th to 28th; the Tar, at Tarboro, 18th to 27th; the Roanoke, at Weldon, 17th to 28th. The Yadkin, at Salisbury, and the French Broad, at Hendersonville, were frozen over with ice 10 inches thick. Similar conditions prevailed in the other years mentioned above. Ice gorges are then somewhat common, without, however, doing much damage.

HOW FRESHETS MAY BE PREDICTED.

There is no regularity in the rising and falling of rivers of North Carolina, and no spring floods, as such. The snowfall in the mountains in winter is rarely heavy enough to constitute a special factor in causing floods, for the reason that there can be no great accumulation of snow. What falls one week is sure to melt the next, and the rivers ordinarily remaining open nearly all the year round, conduct the waters from the mountains gradually to the sea. Owing to the uniformity in the distribution of precipitation throughout the year, the flow of the rivers is nearly as full one month as another.

The success of the river and flood warnings in North Carolina will depend to a great extent on the ability of the forecaster to recognize when the conditions become favorable for heavy rains. Excessive precipitation, and consequent flooding of streams, occurs most frequently, associated with cyclonic disturbances moving from the Gulf of Mexico to Florida and thence up the Atlantic coast, and especially in connection with the regular subtropical storms of August, September, and October. But even the presence of a relatively slight depression over Alabama or Georgia, or off the South Carolina coast, with a high area over New England, will cause heavy rains in the central and eastern parts of the State. Frequently the heaviest rainfall is confined to a limited portion of the State, as, for instance, in August, 1894, when an enormous rainfall occurred in the southeastern portion of North Carolina on the 3d to the 6th. The Cape Fear, at Fayetteville, reached its highest point, 34.4 feet, on the 7th, while the Roanoke was not influenced in the slightest degree.

The distance from Danvilleto Clarksville, Va., is 55 miles; from Clarksville to Weldon, N. C., is 65 miles. If heavy rains occur at the head waters of the river Dan, the highest stage at Clarksville is reached twenty-four hours after the waters begin to subside at Danville; if the rains extend into Virginia over the drainage area of the Staunton, the highest stage is usually attained at Danville and Clarksville on the same day. The river then reaches the full flood at Weldon within about forty-eight hours.

REDBLUFF, CAL.

By Mr. Maurice Connell, *Observer*.

The Sacramento River when flooded is very turbulent. The watershed may be divided into two sections, with the dividing line at or near Redbluff. The surrounding lowland of the southern section was once the bed of an inland sea, and, geographically speaking, is of recent formation. The northern section has a more elevated position, is of a rocky or gravelly formation, the valley more contracted, and the gradient steeper. The bed of the river throughout the whole southern section is being constantly elevated by deposits, while the bed in the northern section is being lowered by erosion. It is evident, therefore, that the danger from overflow to lands of the southern section is becoming greater, while with the southern section it is lessening. The "danger line" twenty years ago is not the "danger line" to-day. The watershed of the upper Sacramento is nearly 10,000 square miles. Within the greater part of this area the winter snows accumulate. If this is suddenly converted into water, the greatest danger from floods in the Sacramento is to be apprehended.

At Redbluff great and sudden rises occur generally with periods of protracted rains in the valley, but as soon as the rain ceases the river falls as suddenly as it rose. No great danger need be apprehended on these occasions.

It is when protracted warm rains in the snow-covered mountains tributary to the Upper Sacramento system occur that damaging floods prevail throughout the whole valley.

It is estimated that within the last thirty years not less than $6,000,000 worth of property has been destroyed by floods in the Sacramento Valley.

For the purpose of flood warnings, there should be a station established somewhere in the snow regions tributary to the upper Sacramento River and a gauge station put in at the mouth of the Pit River. With these precautions taken, the people could have warnings from thirty-six to forty-eight hours in advance. This would give ample time to look up and repair defects in the levees, which are being continuously bored by squirrels and gophers. Owing to the nature of the soil in the levee sections, once the water passes through a gopher hole, there is no stopping it; hence the importance of warnings.

SACRAMENTO, CAL.

By Mr. James A. Barwick, *Observer*.

The levees surrounding this city will stand a rise of 30 feet before endangering the city. On numerous occasions lands which have good and substantial levees on their river fronts have been submerged by back water from the breaking of the levees either above or below their places. If the levees were continuous from Redbluff to Sacramento and below, it would be an easy matter to predict the river stages at this and other points lower down the river; but as the levee system is at present, a rise of 10 to 15 feet in a few hours at Redbluff would scarcely be felt or noticed at Sacramento. As the great watershed of the upper Sacramento pours its drainage into the Sacramento River, the water spreads over the low tule lands by way of the numerous sloughs and by overtopping the slightly built levees. Had this water been confined to the river proper, it would have caused a considerable rise at Sacramento.

The sudden rises at this point come from the American River, whose mouth is only a mile above the city, while the stream is both short and steep, and therefore the water reaches Sacramento with a rush and raises the Sacramento stream rapidly. The water recedes as quickly. But when the Sacramento is high from continuous rains over the entire watershed of northern and central California, and heavy rains occur on the head waters of the American River, raising that stream quickly, danger is then to be apprehended in this city until the American can discharge its supply of water.

DATA FROM THE REPORT OF A. H. ROSE, COMMISSIONER OF PUBLIC WORKS, 1895.

In the floods of 1853 and 1862, the Sacramento River water extended a broad expanse from the Sutter Fort site, in Sacramento, westward to Davisville, standing 3 feet deep across the natural river banks at and near Sacramento. The steamer course from Stockton to San Francisco was, during the latter flood, a direct line across country from Rough and Ready Island to Antioch.

During the high water of March, 1879, the lowlands of the Sacramento Valley, to the extent of 847 square miles, were covered with water. This area includes all flooded for a short period of time, as well as that upon which the water rested for several months. Above the mouth of Feather River, in what may be called the upper flood region, the area covered was about 483 square miles; and below that point, in what is called the lower flood region, the flooded area was about 364 square miles in extent.

The maximum flow of the Sacramento River would have been—

	Cu. ft. per second.
At Redbluff	133,000
At Colusa	89,000
At (above) Feather River	83,000
At (above) American River	136,000
At Sacramento	162,000

A similar study of the condition which prevailed in January, 1894, when the river at Redbluff, on January 15, rose 4 feet higher than in March, 1879, leads to the following result:

The maximum flow would have been—

	Cu. ft. per second.
At Redbluff	152,000
At Colusa	92,900
At (above) Feather River	87,000
At (above) American River	136,000
At Sacramento	156,000

But the high water of January, 1894, did in fact cause a maximum discharge at Sacramento of only about 54,000 cubic feet per second. The river rose only to 21.5 feet on the Sacramento River rod. Had all the water been confined to the channel, none escaping to any of the basins, the water at Sacramento would have been far higher than of the great floods of the past.

That the water surface in 1894 at Sacramento was lower than that of March, 1879, is explained by the fact that in the one case the several flood basins were well filled with water; in the other way they were practically empty at the commencement of the rise, and were therefore practically efficient in retarding the passage of the flood wave down the valley. The highest stage at Sacramento was not reached until January 21.

ST. LOUIS, MO.

By Mr. H. C. Frankenfield, *Local Forecast Official.*

The drainage areas of the principal Missouri River tributaries are given below. Of the rainfall which occurs in the Missouri Basin only 15 per cent finds its way into the river, the remainder being taken up by dry winds and absorptive sandy soils; while in the Upper Mississippi and Ohio basins the percentage is 24.

The tributary effect is very uncertain, as it depends upon the stages of water in the different rivers affected. If the receiving stream is at the high-water stage the effects of a rise in the tributary streams would be totally different from those produced when the receiving stream is low. Consequently the figures given below are largely estimated, and represent what are considered only as average effects.

The tributary effect upon the Missouri River within the State of Missouri is very considerable at times. The tributaries of importance and their respective drainage areas are as follows: On the north side, the Grand River, 7,826 square miles; Chariton River, 3,156 square miles; on the south side, the Black River, 2,732 square miles; La Mine River, 2,700 square miles; Osage River, 15,200 square miles, and the Gasconade River, 3,800 square miles. The first four of these rivers discharge into the Missouri between Kansas City and Boonville, and the amount of their effect can not be estimated to within a reasonable degree of accuracy on account of the absence of the Weather Bureau gauges at or near their mouths. Their additions to the main stream are evidently not quite as large as those of the rivers east of Boonville, especially those of the Chariton and Grand rivers on the north side. These drain a region over which the average rainfall is several inches less than that of the region south of the Missouri, and they consequently furnish less water; the Grand River furnished the major part. The tributaries east of Boonville—the Osage and Gasconade—drain a considerably larger area, and flow through a region which is favored in the matter of rainfall when compared with the north half of the State. The effects of rises in these two rivers appear as a deflection on the Hermann gauge, the normal gauge relations between Boonville and Hermann being disturbed. About one-eighth of the amount of a rise at Bagnell, on the Osage, would appear as an abnormal increase on the Hermann gauge about two days later, and the same proportion is about correct for the Gasconade based upon the stage at Arlington, the rise reaching Hermann in about one and one-half days. Although the area drained by the Gasconade is small, the descent to the river basin is sharp, and it receives water very rapidly, and in much greater quantity, comparatively, than in more level regions.

The principal tributaries of the Mississippi River between Davenport and St. Louis are the Des Moines, Illinois, and Missouri rivers. The Des Moines River does not contribute any considerable volume to the Mississippi, and the effect on the Warsaw gauge at high water would probably not amount to more than one-eighth or one-sixth of a rise just above its mouth. The effect of the Illinois River upon the main stream is somewhat greater, but the absence of a sufficient number of observations at Grafton, Ill., prevent an accurate estimate at this time.

The greatest amount of water contributed to the Mississippi River comes from the Missouri, and it is the controlling factor in floods below Alton, Ill. Of the water which passes St. Louis the Missouri probably contributes from about 55 to 60 per cent at a 13-foot stage, and from about 67 to 70 per cent at a 20-foot stage. That is of course assuming that the stages in the two rivers are approximately alike. The greatest floods occur at St. Louis when both rivers are at a flood height at the same time. Fortunately this condition of affairs is quite infrequent, having occurred but four times during the past fifty-one years, namely in 1844, 1851, 1858, and not again until 1892. In 1844 the highest recorded stage, 41.4 feet, occurred. The floods from the Missouri River as a rule occur later than those from the Mississippi. Of these the greatest occurred in 1883 and 1892.

In the Missouri River Basin during extreme low-water rainfalls of an inch or less produce little or no effect upon the river, for what the soil does not take up is absorbed by the sand in the river. This, of course, is true of only a single rainfall. A second and third in close succession would produce the usual rise.

The scarcity of gauges on the Missouri River, and the absence of discharge figures from a sufficient number of places on both rivers, prevent more accurate deductions, and more or less interfere with the accuracy of forecasts. Hydrographs have not been found to be of much service.

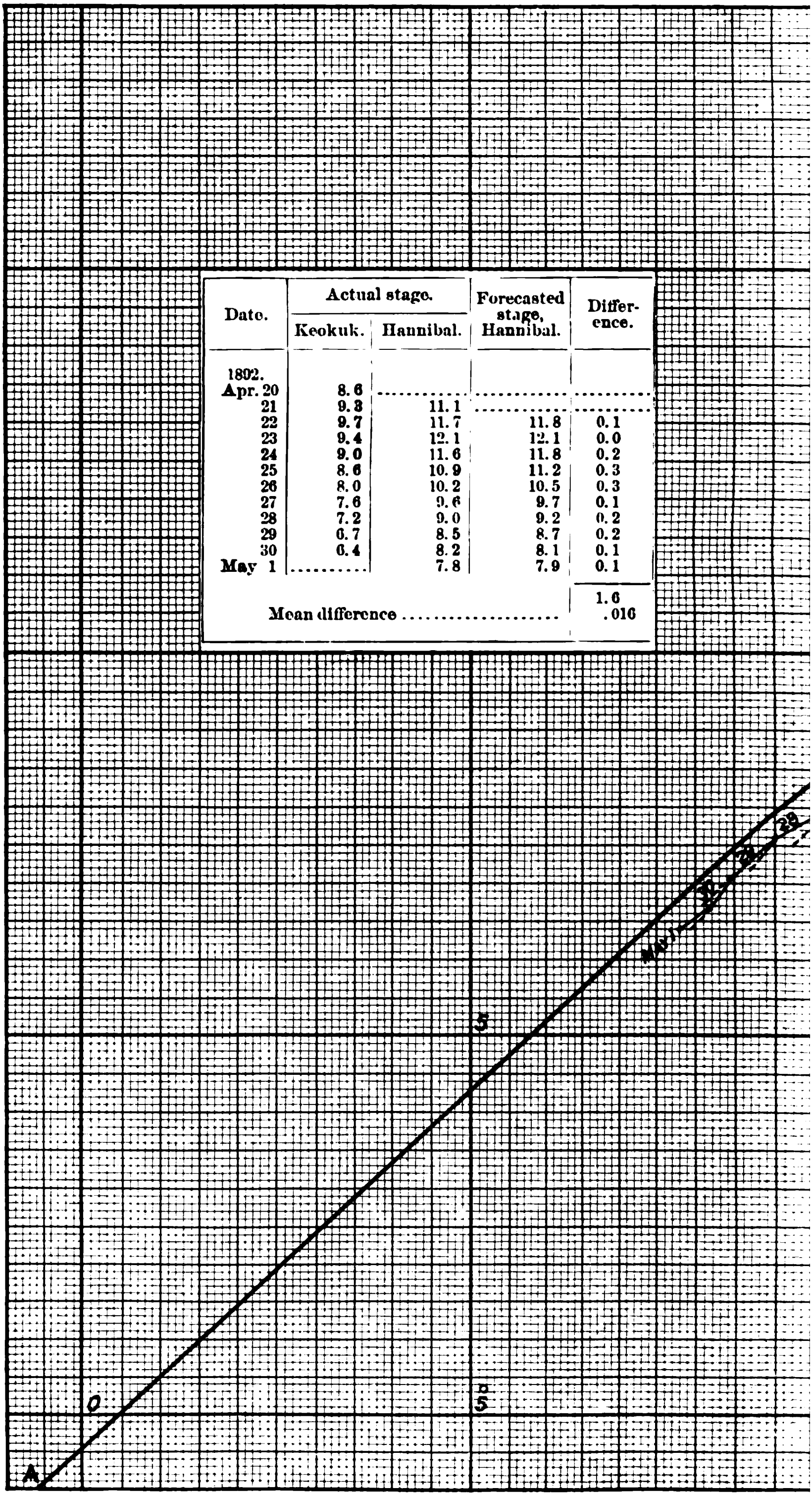
In the vicinity of St. Louis, on both sides of the river, there is no danger of damage by water up to a 30-foot stage. Practically everything is protected up to a 34-foot stage on both sides, with the following exceptions: Even as low a stage as 20.2 feet on the St. Louis gauge will cause the water to run into the marshes on the Illinois side below the East St. Louis Waterworks, but with no resulting damage, and a 32-foot stage will cause the backwater in the Cahokia Creek to overflow its banks and cover the lowlands to the south and east of St. Louis.

At Warsaw, Ill., the new levee protects everything up to an 18-foot stage on the Illinois side, while on the opposite side about 14 feet on the Warsaw gauge will cause an overflow in the Des Moines River bottoms.

At Hermann, Mo., while the danger line is at 21 feet, at which stage the upper bottoms are submerged, at a 16-foot stage some of the lower bottoms are submerged. I would also respectfully invite attention to the following remarks concerning the Hermann gauge, being an extract from the report of the Missouri River Commission for 1894 (Appendix Y Y of the Annual Report of the Chief of Engineers for 1894): "The zero elevation of the Weather Bureau gauge at Hermann is at present 71.23 (above St. Louis directrix); but this value only holds good up to the 13-foot stage, above which the gauge is wrongly graduated, each foot recorded being actually equal to 0.876. According to the rule adopted by the Commission, the Hermann gauge should read from a zero of 68.35. The zero of this gauge has not been kept constant, having been as low as 67.34 previous to 1886, when it was changed to its present elevation." I would suggest that in future publications the zero of this gauge be given as 68.35 feet above St. Louis City directrix, in accordance with the above, instead of 71.7 feet, and that a correction of 2.88 feet be applied to future readings up to the 13-foot stage, and a correspondingly larger one above that stage until the gauge can be repaired. This can probably be done during the next month if the water is sufficiently low. The error above the 13-foot stage probably arose from the fact that the gauge was graduated to inches, approximately, instead of to tenths of feet when it was placed in position some years ago.

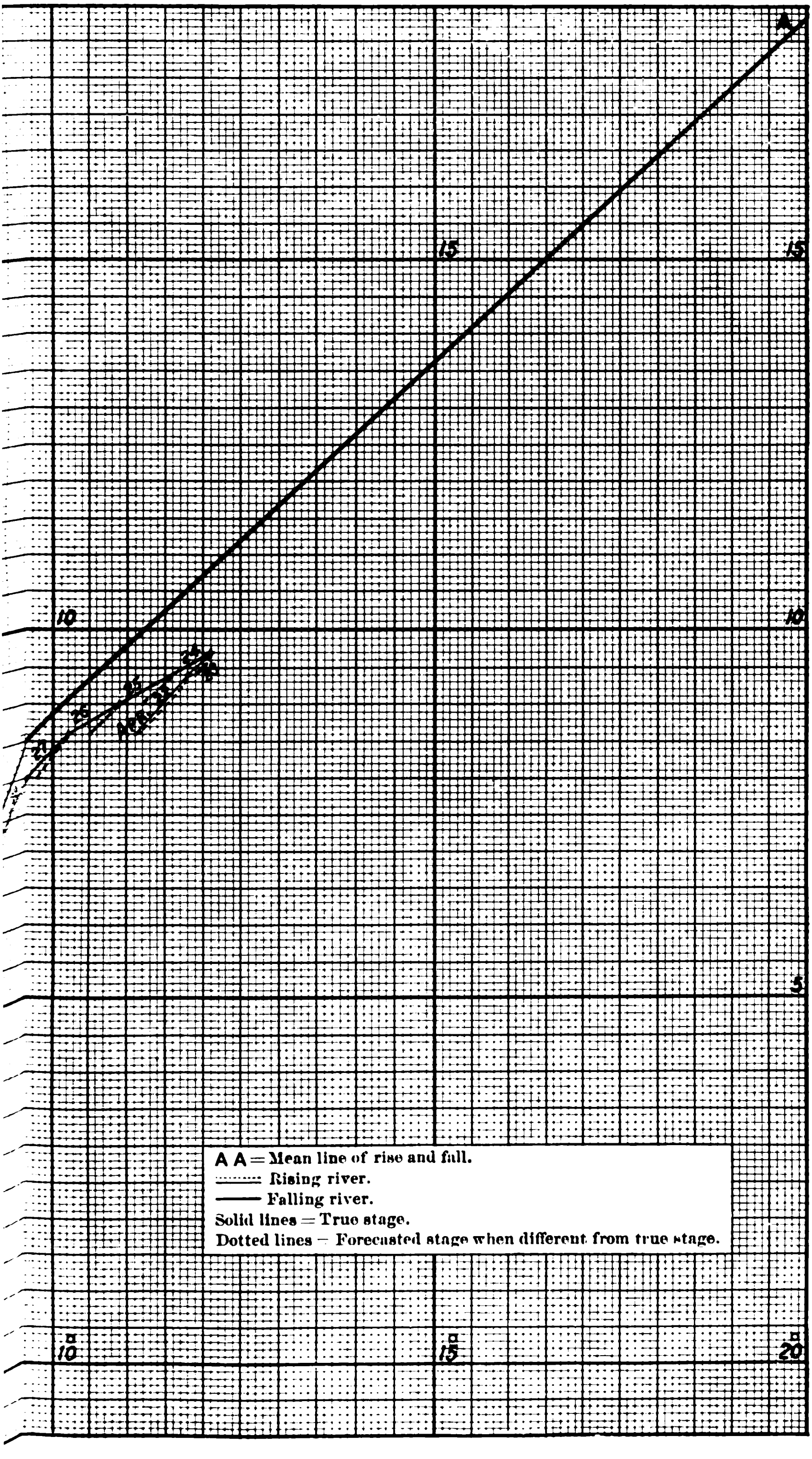
A new water record was made at St. Louis on January 27, 1895, when a stage of 0.7 foot was observed.

A brief description of the system of river forecasting in use at this station may be of some interest. The system is the one elaborated and perfected by Mr. James A. Seddon, assistant engineer of the Missouri River Commission, to whom I am indebted for much valuable information concerning the Missouri River. The system was also used last year by Mr. Hammon, and is as follows: To determine the gauge relations between any two points on the same river, take a piece of cross-section



Date.	Actual stage.		Forecasted stage, Hannibal.	Difference.
	Keokuk.	Hannibal.		
1892.				
Apr. 20	8.6	....	....	....
21	9.3	11.1	....	....
22	9.7	11.7	11.8	0.1
23	9.4	12.1	12.1	0.0
24	9.0	11.6	11.8	0.2
25	8.6	10.9	11.2	0.3
26	8.0	10.2	10.5	0.3
27	7.6	9.6	9.7	0.1
28	7.2	9.0	9.2	0.2
29	6.7	8.5	8.7	0.2
30	6.4	8.2	8.1	0.1
May 1	....	7.8	7.9	0.1
				1.6
Mean difference				.016

FIG. 3.—SYSTEM OF RIVER FORECASTING—KE



OKUK AND HANNIBAL, ONE DAY'S INTERVAL

paper, let the perpendicular scale of ordinates represent the gauge readings at the upper station, and the horizontal scale or abscissas the lower station. The time interval of the water between the two is of course known. Let us assume the time to be one day. Find the point on the cross-section paper corresponding to the gauge reading at the upper station on the first day of the month, and that of the lower on the second day; then find the point for the second day's reading at the upper station, and the third day at the lower one, and so on, connecting each two points by a line, a black line for a rising and a red line for a falling river. Let this be done each day for a year, and then a diagonal straight line of rise and fall can be drawn, along which the stages of the two rivers will invariably meet, if there is no tributary effect between the two and no heavy local rainfall at the lower station. This diagonal line should be a minimum line; that is, one affected by the river itself without tributary or rainfall influence. If lines are drawn for a series of years, a mean line can be obtained which will give better results. With the mean line once obtained, forecasts are made as follows: If the stations are one day apart, as Keokuk and Hannibal on the example inclosed, find the point corresponding to the first day's reading at the upper station, or the ordinate, and the second day's reading at the lower one, or the abscissa. Then find the ordinate corresponding to the second day's reading at the upper station, and trace it horizontally until a point on the abscissa is reached, which, if connected with the point first determined, will make a line parallel with the mean line. This point on the abscissas will be the reading of the gauge at the lower station on the third day, or one day in advance. If several upper stations are used in turn, an accurate forecast for four or five days in advance can be made, unless heavy rains intervene. Tributary and rainfall effects produce a prolongation of the abscissas, and must be estimated as closely as possible. By this system stages can be forecasted to within one or two tenths of a foot for several days in advance.

The system is exemplified on the accompanying chart (see fig. 3) the Keokuk and Hannibal mean line being used with one day interval.

On account of the proximity of the mouth of the Missouri to St. Louis, a combination of discharge figures with gauge relations at Hermann and Grafton is used in forcasting the stages at St. Louis, and forecasts are made for a period of four days in advance.

The time intervals between the stations in this district are approximately as follows:

Mississippi River.—Davenport to Keokuk, 2½ days; Hannibal to Grafton, 2 days; Keokuk to Hannibal, 1 day; Grafton to St. Louis, 1 day.

Missouri River.—Kansas City to Boonville, 1.5 to 2 days; Bagnell to Hermann, 2 days; Hermann to St. Louis, 1 day; Boonville to Hermann, 0.7 to 1 day; Arlington to Hermann, 1½ days.

ST. PAUL, MINN.

By Mr. P. F. LYONS, *Local Forecast Official.*

The Mississippi River at St. Paul is made up of its own water and that of the Minnesota River, the mouth of the latter being about 7 miles above. Both streams are practically within the boundaries of this State. The Mississippi, having its source in the northern part, has the greater watershed, which is, according to the latest determination of the United States Engineer Corps, 19,730 square miles. The elevation of its head water, Lake Itaska, according to Minnesota State surveys, is 1,457 feet above sea level. It drains the timbered, lake, and marsh regions. The Minnesota, with a watershed of 16,350 square miles, part of which is the Dakotas, has its source practically in Big Stone Lake, at an elevation of 962 feet, and drains the prairie and rolling portions of Minnesota and the westerly adjoining State of South Dakota.

The accumulation of snow and ice during winter is the main cause of floods in these streams, and they usually occur in from twelve to thirty days after the breaking up of ice, or the opening of the river, the average date April 1. As a rule, about the time of "opening" a marked rise is observed; it continues to about the middle, and occasionally to the end, of April, but the latter is exceptional; generally the crest of the rise is felt about the middle of that month; but should the rainy season set in early in April, and be rather heavy and continue over to May, the danger of an overflow will not only be considerably increased, but its duration will be extended to May. From the records, and by comparisons, it is found that the most potent factors in promoting dangerous floods are as follows: An unusually wet fall, as to fill up lakes and other water storage places, then a severe freeze, a long and steady winter with considerable and steadily accummulating snow. Such conditions are on record for 1880 and 1881, and the greatest flood on record resulted in April, 1881, and almost solely by the liberation of the ice and snow bound waters of the preceding winter, for the rainfall that spring was very light.

On the contrary, January thaws, which are not uncommon, and February and early March thaws, which are frequent, tend to prevent flood. Clear to fair and very dry weather, and it is unusually dry when clear in early spring—or "breaking up time," as it is familiarly called—is also a mitigating condition, as under such conditions a vast amount of snow is carried away by the high evaporating power of the air; this especially true for the watershed of the Minnesota River. During the "spring rise" the water from the Minnesota can generally be detected here by the muddy and turbulent action. When these signs subside and the river continues high or rising, it may be concluded that the Mississippi is rising and that the Minnesota is falling. There are no observations whatever made of either stream above here, and nothing reliable can be learned as to their condition. A large volume of water liberated from near the head waters of the Minnesota is usually felt here in from five to eight days, and one from about the source of the Mississippi, in from seven to ten days. Fresh to brisk north to northwest winds tend to accelerate and hasten the arrival here of a rise, and conversely as to wind, etc.; however, during the snow-melting time counter results are probable, inasmuch as winds in former instances are liable to be cold and tend to check "thaw," while southerly winds are usually the reverse.

SIOUX CITY, IOWA.

By Mr. U. G. Purssell, *Observer.*

The Missouri has two annual rises or periods of high water, the first occurring usually in March, accompanied by the breaking up of the ice, and resulting from the spring freshets, the melting of snow in the valleys, and the spring rains, and is not likely to result in much damage to property unless ice gorges are formed of such extent as to back the water out of the channel. At the time of the highest water known in the Missouri at this place, which occurred in 1881, such a gorge formed at Yankton, S. Dak., causing the water to spread over the lowlands of Clay and Union counties, S. Dak. In this city very little damage was done. At the mouth of Perry Creek, where the river gauge stands, the river kept within its banks, but it covered the flats in the lower part of the city with backwater, having but very little current and doing but little damage. At the present time that section of the city is covered with houses, and the stage of water would cause serious inconvenience to a large number of people, though little property would be carried away or destroyed.

The second annual rise occurs in June or the first days of July, and is commonly known as the "June rise." It is believed to result largely from the melting of the snow in the mountains, but the rainfall of May and June, being usually the heaviest monthly rainfalls of the year in this section, must contribute a large part of the water in the June rise. A very close estimate of the water in the June rise can be made by considering the amount of accumulated snow in the mountain districts with the spring temperatures. Variable temperatures allow the snow water to drain off gradually, while steady high temperatures bring it down with a rush.

The principal tributaries of this section of the Missouri are the Big Sioux, Vermillion, Dakota, Grand Owl, Cheyenne, Bad, White, Niobrara, Floyd, Little Sioux, and Maple rivers. The most destructive flood in the history of this city was that of

May 18, 1892, in which the water came entirely from the Floyd River, the Missouri showing but a slight rise from the water emptied into it at this time.

From past experience it would appear that the danger to life and property at this place is greater from a flood in the Floyd than from the highest stages of water yet reached in the Missouri. A very destructive flood occurred in the Little Sioux and Maple rivers June 23, 1891, far exceeding any previous occurrence of this kind. So any of the streams mentioned above might under certain conditions be converted from a brook into a mighty river, going beyond its banks, and filling the whole valley through which it flows. This is especially true of the northwestern Iowa rivers, which have narrow valleys, and which drain a nearly treeless region, with numerous small branches which deliver the water of a heavy rain or a melting snow quickly to the main stream.

VICKSBURG, MISS.

By Mr. R. J. Hyatt, *Local Forecast Official.*

The most prominent feature of the work at this station consists in forecasting the approach of high water when dangerous stages of the river are anticipated and crevasses in the levees are feared. In order to forecast intelligently it is necessary to calculate the changes in the upper streams (in connection with the amount of precipitation), including the Ohio and its tributaries, the Missouri, the Upper Mississippi, the St. Francis, the White, the Arkansas, and the Yazoo rivers.

The principal rises in the Lower Mississippi come out of the Ohio, and require about six days en route from Cairo to Vicksburg, four days from Memphis, three days from Helena, and two days from Arkansas City. A rise from the Arkansas at Fort Smith requires about the same time to reach Vicksburg as a rise at Cairo, about six days, and four days from Little Rock. A rise from the White River at Newport takes about four days to reach Vicksburg, and a rise from the Yazoo at Yazoo City about one day.

The St. Francis River and basin complicate the river situation considerably between Helena and Vicksburg, acting as a reservoir for the water during high stages, and holding the river at high water some time after a fall is reported above Helena by pouring an immense volume of water into the river at Helena, and forming a partial dam at that point, retarding the flow of the water in the Mississippi from above. The water from the Mississippi begins to run into the St. Francis basin at a stage of 36 feet on the gauge at Helena, and 29 feet at Memphis. In a similar manner the water from the lower tributaries when high also have the effect of banking up the river above and holding it at an abnormal height, especially when a rise in the Mississippi is coming down. A little effect is produced also in the tributaries by a decided rise in the main river, which causes the smaller streams to back up for a considerable distance.

The rate of movement of falling water is somewhat slower than the progress of the flood wave. The rapid approach of a severe cold wave following a rain storm will generally freeze the upper streams and prevent the water reaching the main river.

From the foregoing it will be seen that a warning of about one week can be given to parties along the river of an impending rise in the Lower Mississippi, thus enabling them to prepare for the flood in advance.

With the exception of the St. Francis, the rivers between Memphis and Vicksburg are navigable. The ice on the river north of Vicksburg caused a temporary suspension of navigation during the month of February, 1895, but it is a very unusual occurrence. The bar at the mouth of the Yazoo River is a very serious obstruction during low water, and at times completely closes the river to navigation from the Mississippi. This obstacle is about to be surmounted by a new channel to be made by the United States Engineer Office which will turn the course of the Yazoo River southward and make it pass in front of Vicksburg through the canal recently dredged from Kleinston about 2 miles below the city, allowing the Yazoo to discharge its waters into the channel of the Mississippi at deep water, insuring navigation during the entire year. This work is now well under way and it will improve navigation of the Yazoo and change the geography of this locality.

At the present time Vicksburg is not approachable by boat during all seasons of the year from the Mississippi on account of the "cut-off" or change in the course of the river, which necessitates the landing of steamboats at the "lower landing" at Kleinston, where the wharf boat is located. At a stage of 17 feet on the gauge, on a rising river, boats come up to the city front through the canal or "passes" leading to the main river. The improvement in the Yazoo River mentioned above will also afford Vicksburg a deep-water channel throughout the year, allowing steamboats to reach the city front at all times. There are two river gauges at Vicksburg, one at the elevator of the Anchor Line, at the foot of Crawford street, and the other at Kleinston. The former is only available at stages of 20 feet and over.

The lowest water on record occurred during the past year, 1894, when the river at Vicksburg fell to 5.2 feet below the zero of the gauge, on November 9 to 14, inclusive. The highest water at Vicksburg of record is 51.1 feet, on April 27, 1862, making an absolute range of 56.3 feet.

The river north of Vicksburg is inclosed by levees, except at the confluence of the Yazoo, Arkansas, White, and St. Francis. The levees on the left bank, or Mississippi side of the river, have withstood the ravages of the floods during recent years, but those on the right bank have been broken by the force of the water and inundated valuable farm land at considerable loss to planters. The damage to the levees, however, has been rapidly repaired, and now bids fair to stand the floods of future years.

Crevasses in the levees are caused by defects in the construction of the levee, crawfish boring through the earthwork, and sometimes by parties cutting the levee for the purpose of floating logs or to relieve the pressure on one side of the river by cutting the levee on the opposite side. Flumes placed in the levee on rice plantations are also fruitful sources of crevasses. The levees are generally sodded for protection against the action of the water. Revetments are also made for protecting the levee, and planks, bags of earth, and burlap are used for holding the embankment intact.

This office is in daily communication by telephone with the levee boards and engineer officers along the river having supervision of the levees and river work, and the river and weather reports are constantly consulted by all interested parties. The river work of the office is greatly appreciated, and the public repose entire confidence in the reports.

YANKTON, S. DAK.

By Mr. H. G. B. Swinhoe, *Station Agent.*

The principal tributaries to the Missouri affecting this locality are the Nebraska, the Cheyenne, and the White rivers, all of which lie on the west of the Missouri and drain the Black Hills country in western South Dakota and eastern Wyoming. It is the large quantity of melted snow brought down by these and other rivers in the spring that causes the annual rise of the Missouri known as the June rise. Sometimes, after a season of excessive snow fall followed by sudden warm spells in early spring, the heavy flow of melted snow and broken ice from these rivers will cause the ice in the upper reaches of the Missouri to break up, while that farther down the river is still intact. This is productive of ice gorges in the narrow parts of the river, at sharp bends, or where numerous sand bars occur, sometimes to such an extent as to cause dangerous and destructive floods. It is generally supposed that the upper Missouri is the source of supply of the extensive artesian basin (or series of basins) which underlies this portion of the country. This would seem to be confirmed by the fact that the pressure of our artesian wells is decreasing as more borings are made, showing that the supply is a limited one.

There is an old Indian saying that a cyclone can never occur between the Missouri and the Jim (or Dakota) rivers, and certainly there is no record of one in this section. The influence of these rivers in this respect would be an interesting study.

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BULLETIN No. 18.—W. B. No. 90.

U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

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OF
CALIFORNIA.

REPORT

OF THE

FOURTH ANNUAL MEETING

OF THE

AMERICAN ASSOCIATION OF STATE WEATHER SERVICES,

COOPERATING WITH THE WEATHER BUREAU,
U. S. DEPARTMENT OF AGRICULTURE,

HELD AT

INDIANAPOLIS, IND., OCTOBER 16 AND 17, 1895.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1896.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., February 1, 1896.

Sir: I have the honor to transmit herewith, with request for authority to have printed in pamphlet form 5,000 copies, Report of the Proceedings of the Fourth Annual Convention of the American Association of State Weather Services, held in Indianapolis, Ind., October 16 and 17, 1895.

This report will prove of interest to the large number of voluntary observers and others cooperating with the Weather Bureau in voluntary capacity, upon whose services the Bureau relies largely for data used in some of its most important work. The proceedings of the three preceding conventions have been published by the Department, and have proved of much interest to those cooperating with the Weather Bureau.

Very respectfully,

Willis L. Moore,
Chief of Bureau.

Hon. J. Sterling Morton,
Secretary of Agriculture.

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FOURTH ANNUAL CONVENTION OF THE AMERICAN ASSOCIATION OF STATE WEATHER SERVICES.

It was originally intended that this association should hold its meetings annually with the American Association for the Advancement of Science, and of the four previous meetings two have been so held, namely, the Rochester convention of 1892, and the Brooklyn convention of 1894. In 1893, and again in 1895, it was found impracticable to meet with the American Association for the Advancement of Science. While the meeting of 1894 was a successful one, the small attendance clearly demonstrated the disadvantages of holding the annual meetings in a city not centrally located. As the American Association for the Advancement of Science met in Brooklyn in 1894, the president and executive committee were of the opinion that if the convention were held in Boston in 1895 the attendance would not exceed that of the Brooklyn convention, and after carefully considering the matter, Indianapolis was chosen as the place of meeting for 1895. As a further advantage, it was decided to hold the meeting of 1895 about the middle of October, after the close of the crop season, when it would be more convenient for the directors of the several services to leave their respective stations. Previous meetings had been held in August. The time fixed for the convention was Wednesday and Thursday, October 16 and 17, the announcement being made on July 12 by the following letter, which was addressed to all State weather service officials:

ANNOUNCEMENT OF ANNUAL MEETING.

AMERICAN ASSOCIATION OF STATE WEATHER SERVICES,
Washington, D. C., July 12, 1895.

SIR: The fourth annual convention of the American Association of State Weather Services will be held at Indianapolis, Ind., Wednesday and Thursday, October 16 and 17, 1895. It was the intention to have the fourth meeting of the association held in Springfield, Mass., in conjunction, as in former years, with the American Association for the Advancement of Science, but in view of the fact that three of the four previous State Weather Services conventions have been held in Eastern cities, it is considered but fair to the directors of the services in the central and western portions of the country that a place of meeting for this year's convention be selected that could be more conveniently and economically reached. Many of the directors, in replying to the letter of April 22 from the president of the association, in which it was proposed to meet in San Francisco, expressed preference for some city in the central portion of the country, and it is believed that in the selection of Indianapolis the wishes of a majority of the directors will be met.

The Chief of the Bureau is anxious that the forthcoming meeting shall be a successful one, and authorizes me to say that as the object of these conventions is to increase the usefulness of the Bureau, permission to attend the convention will be granted all Weather Bureau officials on State weather service work, the necessary absence not to be charged against annual leave.

Information as to hotel accommodations and the building in which the convention will be held will be announced later.

You are respectfully requested to forward to the secretary as soon as convenient a list of topics for consideration of the president of the association in the preparation of the programme of subjects to be discussed at the coming meeting.

Papers upon topics of interest to State weather services are solicited, and if authors of such articles as may be prepared find it impracticable to attend the convention they are requested to forward to the secretary any paper that may be prepared.

Please advise the secretary as early as practicable as to whether it is your intention to attend the convention.

Very respectfully,
H. H. C. DUNWOODY,
President.

The wisdom of selecting Indianapolis as the convention city and delaying the time of meeting till after the close of the crop season was clearly shown by the attendance, which was by far the largest of any meeting held since the organization of the association. The directors of 30 of the 42 organizations were present. Indiana, Iowa, and Nebraska were represented by both the State director and Weather Bureau assistant. Besides the aforementioned, there were present Prof. Willis L. Moore, Chief of the Weather Bureau; Maj. H. H. C. Dunwoody, assistant chief of the Bureau and president of the association, and Mr. James Berry, secretary and treasurer, and chief of the State weather service division of the Weather Bureau.

After correspondence with the various State service officials and securing their suggestions as to the subjects to be discussed, the following programme was adopted:

TOPICS FOR DISCUSSION.

1. How best to secure and retain the services of voluntary observers.

2. What can be done to improve weekly weather crop bulletins and increase their value? What interests are being served by these publications?

(*a*) Should not selected voluntary observers be given authority to telegraph State centers reports of rainfall or other important information on the afternoon preceding date of issue of crop bulletins, thereby giving data for a State rainfall chart?

(*b*) Best means for the collection of data and best form of publication and distribution.

3. Monthly publication of State weather services.

(*a*) Form of publication.

(*b*) Importance of prompt issue.

(*c*) Character of information.

(*d*) Uniformity in style.

(*e*) Preservation in convenient form for reference of the most important data from voluntary observers' records.

4. Distribution of forecasts and special warnings.

(*a*) Can any improvement be made in the present system of forecast distribution?

(*b*) Should flags be displayed to represent forecasts for the current day?

(c) Can forecasts be given wider dissemination in rural districts, and what can be done to prove the value of forecasts in sections where they are not utilized?

(d) Should not forecasts be telegraphed to daily papers of small cities to avoid use of obsolete forecasts given in plate matter used in "make up?"

(e) Value of the logotype system.

5. Equipment and inspection of voluntary stations. Importance of instrument shelters.

6. Along what lines can special investigations be undertaken by State weather services with best results?

WEATHER SERVICE OFFICIALS AND OTHERS IN ATTENDANCE.

F. P. Chaffee, local forecast official, Montgomery, Ala.
F. H. Clark, local forecast official, Little Rock, Ark.
James A. Barwick, observer, Sacramento, Cal.
F. H. Brandenburg, observer, Denver, Colo.
A. J. Mitchell, observer, Jacksonville, Fla.
D. P. McCallum, observer, Idaho Falls, Idaho.
C. E. Linney, observer, Chicago, Ill.
Prof. H. A. Huston, Purdue University, Lafayette, Ind.
C. F. R. Wappenhans, local forecast official, Indianapolis, Ind.
G. M. Chappel, local forecast official, Des Moines, Iowa.
T. B. Jennings, observer, Topeka, Kans.
Frank Burke, local forecast official, Louisville, Ky.
R. E. Kerkam, local forecast official, New Orleans, La.
C. F. Schneider, observer, Lansing, Mich.
E. A. Beals, observer, Minneapolis, Minn.
R. J. Hyatt, local forecast official, Vicksburg, Miss.
A. E. Hackett, observer, Columbia, Mo.
Prof. G. D. Swezey, University of Nebraska, Lincoln, Nebr.
G. A. Loveland, observer, Lincoln, Nebr.
E. W. McGann, observer, New Brunswick, N. J.
H. B. Hersey, observer, Santa Fe, N. Mex.
R. M. Hardinge, observer, Ithaca, N. Y.
B. H. Bronson, observer, Bismarck, N. Dak.
H. W. Richardson, observer, Columbus, Ohio.
J. I. Widmeyer, observer, Oklahoma, Okla.
T. F. Townsend, observer, Philadelphia, Pa.
S. W. Glenn, local forecast official, Huron, S. Dak.
H. C. Bate, inspector, Nashville, Tenn.
I. M. Cline, local forecast official, Galveston, Tex.
G. N. Salisbury, observer, Seattle, Wash.
H. L. Ball, observer, Parkersburg, W. Va.
C. M. Strong, local forecast official, Milwaukee, Wis.

There were present the following-named voluntary observers and forecast displaymen:

B. F. Hole, Butlerville, Ind.
F. G. Erskine, Pleasant Ridge Park, Ky.

There were also present local forecast officials, H. C. Frankenfield and F. J. Walz, in charge of the Weather Bureau offices at St. Louis, Mo., and Davenport, Iowa, respectively.

The convention was called to order at 10.30 a. m., October 16, by the president, Maj. H. H. C. Dunwoody, who, after the call of the roll, addressed the meeting as follows:

ADDRESS OF THE PRESIDENT.

To one so long identified with the work of State weather service organizations, and who has watched with keen interest their progress from year to year, as has been the case with me, the greeting of so large a number of officials in charge of these organizations, with some of their voluntary colaborers, as are assembled on this occasion, is indeed a very great pleasure. I may properly state at the beginning of my remarks that it is a singular coincidence that the first convention of voluntary observers ever held assembled in this city thirteen years ago. And while the convention was called in November, 1882, a month later than now, the very dates on which it met are identical with those set for this convention, namely, the 16th and 17th. On that occasion we were honored by the presence of the chief executive of the State, Governor A. G. Porter, and my friend Captain Connor, whom I am glad to say is with us to-day. Interesting addresses on the subject of State weather services were delivered by both these distinguished gentlemen, and I also recall that several very able addresses on subjects pertinent to the State weather service were delivered by voluntary observers of Indiana. Among the latter who addressed the convention were Prof. Charles G. Boerner, of Vevay; Mr. William Dawson, of Spiceland; and Mr. John Chappelsmith, of New Harmony.

Having first suggested the organization of State weather services, as auxiliary to the National Weather Service, to General Hazen in 1881, I was sent by him from Washington to represent the Signal Service (at that time in charge of the Weather Service) at the voluntary observers' convention to which I have alluded. In the following year, under orders of the Chief Signal Officer, I made an official tour of a number of States for the purpose of conferring with the governors and other State authorities with a view to organizing State weather services, or creating an interest in such work. As the value of the State service was readily recognized by the officials with whom I consulted, I met with much encouragement, and during the following and succeeding years State weather services were organized with rapidity. The good work begun by the pioneer observers of Indiana has been carried on during the succeeding years with valuable results, the State to-day having a very efficient organization under the able management of Prof. H. A. Huston, of Purdue University, and his assistant, Mr. Wappenhans, local forecast official in charge of the Weather Bureau office in this city.

By 1892 the entire territory of the United States was covered by State weather service organizations. With the exception of the six New England States embraced in the territory of the New England weather service, and Maryland and Delaware, covered by the Maryland weather service, each State or Territory has its separate service.

During the latter part of 1885 the Chief Signal Officer issued a letter to the directors of the several State weather services in operation at that time suggesting a convention of directors. This suggestion was favorably received, and a convention was arranged for and held at the Smithsonian Institution in Washington, D. C., February 24 and 25, 1886. This was the last assemblage of State weather service directors until the summer of 1892, when, at the suggestion of Prof. Mark W. Harrington, Chief of the Weather Bureau, arrangements were made for a convention, which was held in Rochester, N. Y., August 15 and 16, in conjunction with the American Association for the Advancement of Science. At this second convention of State weather service directors, at which eighteen services were represented, a permanent organization known as the American Association of State Weather Services was effected. Since then it has met annually, the two conventions immediately succeeding the first one being held in Chicago and Brooklyn. These gatherings of State weather service officials and their colaborers have resulted in great good, affording means for the exchange of views with respect to the methods of collecting and distributing weather and crop information. The published proceedings of the several conventions have been received with much interest, both by the officials engaged on State weather service work and the voluntary observers, weather crop correspondents and forecast displaymen who have been supplied with copies of the published reports. At the Brooklyn convention of last year it was very gratifying to the officials of the State Weather Services and myself to have in attendance several voluntary observers, and I am happy to state that we have with us to-day quite an attendance of voluntary observers, forecast displaymen, and crop correspondents of Indiana and neighboring States, indicating a growing interest in our work.

Having always been a sanguine believer in the value of these local services, it is with much gratification that I am able to say that the past year has been marked by especial activity in the several lines of work. A great improvement has been made in the character and form of a number of the monthly publications; but with respect to publications, the most marked improvement has been made in the form of the weather crop bulletins, which, with but a few exceptions, have been issued in printed form, being vastly more attractive and convenient than the milliograph bulletin of former years.

The meteorological data furnished by monthly reports, giving summaries of the observations taken, are of incalculable advantage to engineers in charge of public works in making their calculations as to the capacity of sewers, reservoirs, etc. Some of the most striking illustrations of the data being collected and published by the New York State weather service were presented to the legislature of that State during its session last winter when an effort was made, on the score of economy, to cut off the appropriations for the State weather service.

The liberal policy of the honorable Secretary of Agriculture toward these services enables the Weather Bureau to do a great deal more now than in former years. During the year ending June 30, 1895, over 400 voluntary observers were furnished with the usual instrumental equipment of a voluntary station, and the number of stations now in operation has reached such proportions that the distance limit considered in the establishment of new stations has been reduced to 25 or 30 miles, the former limit having been fixed at 50 miles. The past year, in the work of distributing weather forecasts and special warnings, has been without precedent in the history of the Weather Bureau. Through the various State weather service organizations the daily forecasts or special warnings are sent to over 22,000 addresses, and with the arrangements now in hand the number is being rapidly increased. To the Post-Office Department, and especially to the present Postmaster-General, is the Weather Bureau greatly indebted for the hearty cooperation received in the distribution of forecasts by mail. The letter issued by Postmaster-General Wilson in May, 1895, and published in the Official Postal Guide for June, inviting postmasters throughout the country to lend their aid in the work of distribution was followed by many voluntary offers from postmasters, and a large number of distributing centers under the logotype system has been arranged for.

I recall the fact that less than two years ago I recommended to the honorable Secretary of Agriculture the expenditure of a small amount—I think it was about $200—for the purchase of logotype outfits, and the practical and valuable feature of this suggestion was at once fully appreciated, and the amount requested for the experiment was freely authorized. The results fully justify the small expenditure, and to-day there are thousands of communities in this country which should thank Secretary Morton for the daily receipt of weather forecasts which previous to his administration it was impossible to secure.

Through State weather services and local organizations the benefits resulting from the Weather Bureau work has been more largely extended to the people during the past two years than in any like period in the past. The scientific work of the Bureau has been heartily supported and directed into proper lines of investigation, whereby the benefits of our service are being rapidly extended to agricultural communities.

The experience with the logotype system, which has now been in operation nearly two years, has been highly satisfactory, and it has proved the most convenient and economical means of distributing weather information ever tried by the Weather Bureau. With this system it is believed fully 90 per cent of the post-offices in the United States may eventually be reached by mail in time to make the forecast of benefit. In some States this work has not received the attention that the plan merits, but its success elsewhere proves that it can everywhere be made a most valuable means of communicating weather information. Directors of State weather services should, where not already done, fully acquaint themselves with the facilities of the cities and towns of their respective States, and correspond with the postmasters in towns having the best facilities for reaching outlying post-offices, with a view to establishing logotype distributing centers. What has been done in Ohio, where nearly 2,000 post-offices, or about 60 per cent of the entire number in the State are furnished with the forecasts by mail, can be done to greater or less extent in other States. This plan is especially commended to the attention of the directors of services who have, as yet, not developed this feature of the work as fully as they should.

In no year since the inauguration of the weather crop service have the bulletins, both State and national, been so largely sought for and closely watched as during the season just closed. Many of the State bulletins have been so enlarged as to attain proportions exceeding the national bulletin of a few years ago, while the national bulletin is now larger and more complete than in any previous year.

There is a great future for the Weather Bureau and its auxiliaries, the State weather services. The people are becoming more and more familiar with the work that is being accomplished for their benefit, and more fully realize its value. The Bureau is criticized for its shortcomings, and this is right; but when it accurately forecasts weather conditions thirty-six hours in advance at least eight times out of ten there is a good balance left to its credit after deducting the charges for failure. In my opinion, the public will never consent to an abridgment of the services now rendered by the Weather Bureau, and extension, rather than curtailment, will be the demand.

After consulting the directors of the various services, a list of topics for discussion has been prepared, and will furnish the programme of the convention. The discussion of these subjects and others that may be suggested can not but result in profit to those directing the operations of State weather services, and I hope that with this large attendance the work of this year's convention will prove even more valuable than the highly satisfactory results of previous conventions.

The journeys to these conventions to many are attended with great personal expense, and, in my opinion, it would be difficult to give stronger evidence of your fidelity to duty and interest in the work in which you are engaged than by your attendance. Some of you have arranged for brief vacations, well earned, after the convention adjourns, and it is my earnest wish that you will all have a profitable and pleasant experience. In conclusion, I desire to thank the members of the association for the honor they have conferred upon me in electing me president during the past three years.

At the conclusion of the address by the president he introduced the president of the board of trade, Mr. Gordon, who extended to the members of the convention an invitation to visit the rooms of the board and to a banquet.

DISCUSSION AT WEDNESDAY MORNING SESSION.

The **President**. I suggest that we take up now the regular programme. The first subject for discussion is, "How best to secure and retain the services of voluntary observers." I hope to hear from a good many of you on this topic. You are all anxious to please the voluntary observers, and it is important to increase the number of them, as upon the faithful work of the voluntary observers very largely depends the success of our organization. The subject is now open for discussion.

Mr. **Mitchell** (Florida). I think this is one of the most important questions we have to contend with, that is, in some of the States. I mean to get good satisfaction from those who serve throughout the State. We are all aware that cheap service, as a rule, is poor service. While this is not generally the case in State weather services, we frequently find it so in all walks of life. As far as my State is concerned, I think that by enlarging the circulation of the publications of the different States—that is, those that have sufficient showing to issue a monthly publication—would be a very important feature to voluntary observers. Send them out over the country, and encourage publications from them, so far as the conditions will admit. I am satisfied that this will be a very important factor and give good satisfaction. I am satisfied that it will prove beneficial to the State of Florida, and I say also of other States.

Mr. **Bronson** (North Dakota). Mr. President, do not all of the voluntary observers receive such publications now?

The **President**. I think a great majority of them do receive copies of such publications. I have always understood that they were furnished by the Bureau.

Mr. **Bronson** (North Dakota). I think the best method of retaining the voluntary observers is to furnish them as promptly and as completely as possible with all information, whether taken from their own State or from other States. I would suggest as a matter of detail, in addition to that which has already been stated, that we have more or less correspondence with the voluntary observers. I think if it could be arranged we should furnish them with letter heads in order to establish communication between them and the directors. I think it would very greatly help along the line to furnish them with all necessary expenses—to put them in correspondence.

Mr. R. M. **Hardinge** (New York). The State of New York has never had any difficulty in retaining the services of the voluntary observers after having once secured them, and in order to give them some little return for their services we have subscribed for a number of monthly journals and have distributed them from station to station, and we find that the observers are very much interested in them. The trouble is not at all in retaining their services, but there is trouble sometimes in getting rid of some of them. That is the most difficult part of our work. I suppose my experience in that line is no exception to ma others. Some of our observers want to take observations at any time—at any and all hours of the day; they make requests for barometers, hydrometers, and so on, and they wish to go into the work just the same as a man who is getting a good salary for the work. Of course we have to discourage such men, and in a way that will not be offensive to them. We have to let them down very easily. I think the voluntary observers are very much encouraged by being visited by the directors. It is a source of profit to them to be in touch with the directors and keep in touch with them. Write to them often. You have got to keep them interested in their work so that they will be interested in you, and naturally when they are interested in you they will become interested in the work you have for them to do. I have never had any difficulty at all.

Mr. **Bate** (Tennessee). It requires a great deal of knowledge of human nature, I might say, to work with voluntary observers. There are some of them who will be very much interested in the work for a few months, and then the novelty wears off and there begin to be gaps in their reports. Others will start out with almost any kind of an outfit and do good work. I have got some observers that have been taking observations with the same thermometers used in 1883, in use twelve years or twelve years and a half, and they have sent in their reports without a single break. Of course where you have observers like that there is no trouble at all. I think one of the best methods of getting good voluntary observers is to let them know that they are going to have a No. 1 outfit, and if they are interested enough in the work they will continue in it. This has been my experience, although I have not had very much during the past few years. It is a good idea to keep a voluntary observer impressed with the importance of his station as a factor in making the climatic history of his State.

Mr. **Hersey** (New Mexico). I think the different conditions of the different States and Territories require entirely different methods of securing and retaining voluntary observers. Now, in New Mexico we have various kinds of population, a large part of it being of Spanish descent. Many of the Mexicans are not capable of attending to that kind of work, and so we have to rely on the American element. One of the surest ways of retaining observers that I have found is to become personally acquainted with them, if possible. I have never lost an observer that I wished to retain, by reason of being personally acquainted with him. They are interested in the work, and they do not like to drop it, for fear of wounding the feelings of their friends. In that Territory—New Mexico—some of our best observers are the railway station agents. I made arrangements with the superintendents of some of the main roads running through the Territory to instruct their agents to act as voluntary observers. They are usually a well-educated class of people and well fitted for such work. Some of our best reports come from them. By making their acquaintance personally and interesting them you can almost always retain their services. This is one of the most valuable means that I have ever found.

Mr. JENNINGS (Kansas). In selecting voluntary observers I think you should first locate your town, and then visit that town. I do not think the scheme of recommendations from the postmasters will work very well. It depends altogether upon how the postmasters look at the question as to who they will recommend or suggest for the work. If you go to a town and talk the matter up, there is always some one who will be more or less interested in the subject, and then you can form a better estimate of your prospective observer. You can probably in this way get an observer that you can retain all the way through. In the eastern part of Kansas we have no difficulty at all in retaining the services of observers, especially if they are desirable ones. In the western part of the State it becomes much more difficult to keep them, simply from the fact that many men locate there and, after trying to get rich for a year or two and finding they can not so rapidly, they move away and locate somewhere else. In other words, the western part of the State is like the sands of the desert—carried around by the winds. After awhile you write to the postmaster to inquire why letters have not been answered, and he says in reply: "Why, that man has gone. He has left some things here which I think are for you." I would like, so far as I am concerned, to know of some good method of getting good observers stuck in the sand—get rooted out there. We have one in the southwestern part of the State, a civil engineer, and he would make a good observer anywhere. He wrote me at one time, suggesting that some one be appointed at Richfield, as it was a little nearer the railway and it would be easier to get the mail from there. I wrote back, saying that I would be very glad, indeed, to have some one at that place immediately, but that we would rather not lose his services. His work is nearly perfect, his reports come in regularly, and in his whole work there are not more than half a dozen errors in the whole year's time.

Now, as far as railroads are concerned, I am glad to hear somebody say a good word for the railroads. I think the Union Pacific Railroad has about forty or fifty stations between Brookville and Denver, and I corresponded with some of the people at those stations—with some of the voluntary observers along the line—in regard to their reports. I wrote to the superintendent of the road at Kansas City, asking him to inspect some of the stations. This was in February, 1887. Finally, I started out myself, and found that in a good many places the exposure of the thermometer was very poor. I found them usually in a little box 10 inches wide and probably 15 inches high, with a tin tube running out from the top for ventilation, and they would get very warm during the day. In many instances the boxes were placed on the north side of the buildings, but everyone knows that railroad buildings do not stand with the points of the compass. The railroads are very crooked and are built all around and over the country, and the depots are built alongside of the track whichever way they happen to be. In some places the thermometers were exposed to the sun, and they had a temperature of 112° and 115°. One station reported very little rainfall, and at the next station there was a tremendous rainfall, the observer reporting from 3 to 4 inches every time it rained. He had his rain gauge under the rain spout that carried the water off the depot. He said his instructions were to catch the rain water. An agent asked me one time, "How much rain do you think we had here last night?" I replied probably 0.76. "Well," he said, "it is pretty nearly an inch." It is my experience that the best method of securing observers is to pick out your town first where you want one located, and then go there in person and get acquainted with the business men, and state your case to them. I usually take with me a copy of the National Review and show it to them. By the way, our State Review has not been printed this year because of a little difficulty between the State board of agriculture and the printing commissioners. I take this National Review to them and say to them, "Now, here is a bulletin that is printed every month, twelve times a year, and is sent all over the world. People don't know that you have a town here, but they do know that there is a town of McPherson next to you over there because the name appears in this list, and you ought to have pride enough about you to advertise this town all over the world. If you can get some man to take charge of a set of instruments which the Government will provide, why you can get your town advertised for nothing twelve times a year." There has sometimes been considerable expense attached to the reaching of these towns, as they were not situated by the railroads. The bicycles are of very great advantage, because you can strike across the country and save time and expense. I think the weather bulletin when printed and sent to the observers goes a long way in retaining their services. A great many publications are exchanged. You have all heard of the Hay Trade Journal, published in New York, and the American Swineherd, published in Chicago, and I might mention a good many others. They are of no particular use to our offices, but we distribute them to parts of the State where they are interested in hay and in swine and so on, and we find they are very greatly interested in them.

The PRESIDENT. We have with us a gentleman who has had a great deal of experience in securing and retaining voluntary observers, and he probably has more information on the subject than most of us. I shall extend an invitation to him to make any remarks upon this subject that he may wish, or upon kindred subjects. We would like to hear from the Chief of the Weather Bureau.

Professor MOORE (Chief of the Weather Bureau). I do not know whether I have lost my membership in this organization or not by being called to a higher position; but anyway, my interest is with you and my heart is with you. I spent three years actively in the State service work, and I can say that I have never had cause to regret my connection with this important branch of the Weather Bureau. Nothing will ever cause me to disparage the work done by the State weather services, but rather it is my desire to see it extended, and become more comprehensive in its scope.

I hardly think, Mr. President, that I shall talk much on the subject you have given me. I am too full of something else. I am aware that you are all members of the Federal service and that you are all officials of the United States Weather Bureau, as well as directors of State weather services. Now, the work of your State weather services during the past year or two has been so admirably outlined and referred to by your able president that it is not my purpose to enter into that at all, although I heartily concur in everything he has said. I would rather speak to you of the attitude of the Department of Agriculture to the Weather Bureau as a whole, than as a State weather service system. I wish to speak of the policy of the honorable Secretary of Agriculture toward the Bureau. In calling me to the position I now hold, he informed me that I should enter the office free and untrammeled; that I should enter into it with the single and only purpose of making it the greatest weather bureau in the world, and that to accomplish that end there was but one policy to pursue, and that was to recognize every man for his merit, to make recommendations for promotion entirely upon the record of the men, without regard to political considerations and without regard to religious affiliations—that only the merit of each worker should be considered. I have tried to impress upon all the fact that I shall not waver in my duty, or allow other than honorable motives to influence me in my recommendations. I can not make this point too strong, for our whole success and the whole development of the Bureau depends upon our making it a merit system, pure and simple. Within the past ninety days there has been a professor of meteorology selected, and there has been a weather forecaster selected; in both cases they were men who had made especially high averages in their work. The one selected for professor made the highest average in forecast work, during the past year, of all officers at Washington. He was selected accordingly. The national forecaster was selected because in recent competitive examinations he made the second highest place. In both cases they were selected for their ability and devotion to duty. Economy has been rigidly practiced in the Bureau in cutting off all unnecessary compilation of data, as I presume you have all noticed by the recent orders which have gone out to you. This has enabled us to dispense with the services of some few workers who have not been up to the standard of efficiency, and has also enabled us materially to advance in salary seventy-eight of the deserving men of our service. Not only has the letter of civil service been observed, but the spirit has been steadily carried forward.

I know that your deliberations here as State weather service directors are for the good of the Weather Bureau, and your devotion to this cause is certainly admirable, coming here each year as you do at your own expense and each year growing and increasing in knowledge. This is the finest presentation the State weather service men have ever made, and I hope that your deliberations will result in pleasure to yourselves personally as well as in profit to the Bureau.

Mr. **CHAFFEE** (Alabama). Before taking up the next question, I want to say that I agree with the director from Florida that this question we have been discussing is one of the most important we have to contend with. Now, as to the best means of obtaining voluntary observers, I would say nothing; that point has already been sufficiently discussed. But one of the best means of retaining them that I know of is to let them know that their work is being used for the benefit of their State. I always impress that fact upon them. When I find that they are losing interest, I write them and again impress that fact upon their minds. It is one of the most telling features, to my mind, to let them know that their reports are being used for the benefit of their State in advertising to prospective immigrants and investors the climatic resources and advantages of their section.

Mr. **McGANN** (New Jersey). I think one of the best and surest methods of retaining the interest and the services of the voluntary observers is to insure a prompt and accurate publication of the essential points of their reports. Men generally like to see their names in print. There is not one of us that does not. I think that method helps the men more than anything else. After we have their reports, print them and let them see that they are printed and that we have had them printed accurately. Print special remarks from their stations which they make. They like to see them. I think it appeals almost directly to each individual, and is a matter of the greatest importance to them. As to the method of securing observers, in the Central States at least, there is a growing organization which I believe will help us a great deal if we will use them, and that is the farmers of the different States. From among the farmers, I believe we can secure a good many voluntary observers of the very best type. The men generally live on farms, which would afford a reasonably good exposure for instruments, and they would take a daily record. They are permanent residents, and they are men, as we all know, who do their work well. They are always at home, always on hand; they are men who realize that the meteorological observations are of the utmost importance to them and to their crops and to their farms in general. As the question of drainage is being discussed more and more, the question of rainfall also becomes more important to the farmers. There is no doubt in my mind that from these institutes voluntary observers could be obtained who would serve almost continuously; they would make permanent and valuable observers, it seems to me, and it is the most promising outlook I have yet seen in our State.

Mr. **Schneider** (Michigan). I have been very successful in placing voluntary observers in the care of fire departments in towns large enough to afford a fire department, or in towns where there is a system of waterworks where there is a pumping station day and night. I have placed many voluntary observers very satisfactorily in this way. This, of course, pertains only to the larger cities, but it becomes permanent, and is something that lasts for all time. I always equip my observers with a good set of instruments and see that there is good shelter. They are usually a very intelligent set of people, and they carry on this work very successfully, as they are always on hand. Another point to bring up is the payment of voluntary observers. In our State, four or five years ago, under the régime of Mr. Conger, we paid our voluntary observers from an appropriation made by the State $1 a month, and it is wonderful how much you can do with the voluntary observers if you make their work a matter of dollars and cents. Of course I know that in this voluntary observer work you have got to treat them cordially and furnish them with all your publications, etc., before they will sometimes resume their duties, but in a matter of dollars there is no difficulty in making a permanent affair out of it, and it is my object to make them as permanent as possible.

Dr. I. M. **Cline** (Texas). Over the eastern half of the State we can get more observers than we desire. Some of them are railroad men, and they make good observers. We do not have the advantage of many railroads in the western portion of the State where observers are most needed, and hence can not draw on them for observers. We manage to work up considerable interest among our voluntary observers by occasional visits to fairs, farmers' institutes, etc., where we meet voluntary observers and talk with them. Another feature which we are putting forward in Texas, and one which interests the voluntary observers and demonstrates to them the practical value of their work to the State, is the issue of special bulletins devoted to climatology, agriculture, horticulture, etc., local and general. This does more to enliven an interest in the work than anything I know of. We have no trouble in securing and retaining voluntary observers over the eastern portion of the State, but in the western portion we have a number of counties sparsely inhabited, and those who inhabit some of them are, as a rule, herders, who have no personal interests. Of course it is very difficult to reach those counties. The land is owned by nonresidents; but when we can reach them they generally arrange to have some one in their employ take hold of the work, but even then we can not always find one who can keep up the records; and as for farmers' institutes and such organizations, we have none in west Texas. In that part of the State the question of irrigation is a great one, and our people want all the statistics of rainfall that they can possibly get; and I find that wherever there are men who have interests and are properly located they gladly take hold of this work in their section, realizing that it is to their own benefit.

Mr. GLENN (South Dakota). Voluntary observers are doing a great work and I would rather have them interested and earnest in that work. We should lose no opportunity of showing our appreciation of what they do and what they have done. We are earnest and sincere in our efforts to build up State weather services, and by infusing this spirit into the observers, we not only get better service but are more liable to retain them. This policy has been successful in my State. The receipt of every Form 1009 and 1067 is immediately acknowledged in a courteous letter to the observer, and he is thanked for the report and his promptness in rendering it. My greatest cause of loss in voluntary observers has been due to their departure from the State.

Mr. SAGE (Iowa). Mr. President, there are observers and observers; good observers are born, not made. Now, as to the observers in our State. There is no trouble at all in getting them, but the trouble is in the matter of selection; not to find a man, but to find the right man. There are more men offering their services in Iowa than we can begin to supply or equip with instruments. I think the thing for the Government to do is to enlarge its appropriation in order to get instruments that can be utilized to good advantage. I believe that we should be more liberal in supplying instruments, and that is the greatest difficulty we have in Iowa—the lack of funds for this purpose. There is another point I would like to speak about—the railroads. They become intensely interested in this work, and appreciate fully the value of this service to their own interests. I have had letters from presidents of roads, and from superintendents of construction, and from chief engineers, asking about this matter of rainfall. They want the information for the construction of their culverts and bridges. And I have also had conversation with some of the different men in regard to furnishing rain gauges at the stations. They say that they will give us free telegraphic messages at all times if we will furnish the instruments. This is what we ought to do. I think, however, the Government of the United States ought to do a part in this matter, and the people in Iowa are willing to go more than half way. We can very greatly enhance the value of this service by local cooperation, by utilizing all local sources of information. There is nothing that can be done in this world without cooperation.

Dr. R. J. HYATT (Mississippi). Mr. President, I have found that one of the best means of securing voluntary observers is by selecting them from the large number of crop correspondents throughout the State. Any man who will render a good crop report will also make an accurate voluntary observer. I have a great many excellent crop reporters, some of them having instruments of their own, and from this source the number of voluntary observers can be increased very satisfactorily. I have had no trouble in retaining the services of voluntary observers after they are once well started and instructed in the work of the service. They take a pride in the publication of their reports.

Mr. **Strong** (Wisconsin). On the subject of procuring or retaining the services of voluntary observers, I think there is nothing so effectual as a frequent inspection of their work; to visit them and become acquainted with them. I find this to be the case in Wisconsin, where the men take the greatest interest in the welfare of their towns, and I find that they are willing to contribute their time for the benefit of their immediate region.

Mr. **McGann** (New Jersey). Speaking of a small remuneration, say $1, I don't believe that would amount to anything with the voluntary observers. Without it, I think the voluntary observer has an interest in the welfare and development of his country, and that he is giving his services as a public good for the public benefit, and the way to retain him is to visit him and become acquainted with him, and make him feel that his services are of value to you. Of course this is difficult for the directors to do at their own expense; we can hardly expect it of them, and we can not see our way clear to allow them Government transportation as yet. But I do want to see the day when an allowance can be made for this purpose—enabling the directors to visit and inspect the stations of their voluntary observers without pecuniary loss to themselves.

The **President**. Now, gentlemen, if there is nothing further on this subject, and as it is half past 11, we will adjourn for the purpose of visiting the board of trade in their rooms. They have invited us to do so. We will be on hand again at 2 o'clock.

The convention then adjourned until 2 o'clock p.m.

DISCUSSION AT WEDNESDAY AFTERNOON SESSION.

The **President**. I have just received the following telegram from Mr. Pague:

> Portland, Oreg., *October 16, 1895.*
>
> *The President American Association of State Weather Services, Indianapolis, Ind.*
>
> My compliments to the members of the convention. Wish you all unbounded success in all endeavors, and trust the meeting may be beneficial and enjoyable. Regret my inability to be with you. The people of Oregon would like to have you meet in Portland next year.
>
> B. S. Pague.

We will now proceed with the next subject on the programme, which is No. 2, and is one of the most important with which we are identified: "What can be done to improve weekly weather crop bulletins and increase their value?" I think it will be well for the members of the association in discussing this subject to make their remarks applicable to their localities, and thus give the members of the Association more detailed information. These bulletins afford an excellent means for studying the interests of the several sections that may be benefited or protected through a foreknowledge of weather changes, and I think it would be well for everyone charged with the duty of making forecasts to make a careful study of the interests that may be served in each locality, so as to be fully informed concerning the crops liable to injury from such changes. I find the benefits resulting from the forecasts largely depend upon the understanding of the forecast official as to the special interests the forecasts may serve; therefore, in discussing these questions, we must remember that much responsibility rests upon the man who prepares the forecast. I would like to hear from some of the gentlemen on the subject, "What can be done to improve the weather crop bulletin and increase its value?"

Mr. CHAFFEE (Alabama). I do not wish to interject anything foreign to the topic under discussion, but I would like to say here, in the interests of the rice growers of southeast Alabama, and the same may be said for the lowland rice planters of the Carolinas that warnings of high winds are of vital interest to lowland rice planters at that stage of the crop when it has nearly matured. The heads of rice are then full and nearly bursting; any high wind will switch about and shake out a large amount of rice on the ground. Now, those planters engaged in wet culture of rice, all of whom have their fields dyked around, can upon receiving warnings of high winds open their sluice gates, let in the water, and flood the rice nearly up to the heads; the water holds the stalks steady and prevents damage by wind. When the danger is past the water is withdrawn. The water does not injure the rice; and I know of several cases where the action I have mentioned has saved a rice crop.

Professor SWEZEY (Nebraska). Mr. Chairman, I would like to say a word about the value and appreciation of the maps. Now, for three years we have published a map giving the actual amount of rainfall. These maps have been so highly appreciated in our State that it seems to me it ought to be taken up in every State. I think we are justified in saying that the map is appreciated, inasmuch as it is copied by the Lincoln and Omaha dailies, by the Nebraska Farmer, our leading agricultural weekly, and by the Lincoln Newspaper Union, by which it is sent out widely to the country papers.

As to the cost of the outfit, of course that depends upon what you have to buy. It consists of two rather heavy iron plates, with metal bars running lengthwise between them, and these are clamped together. The blank map answers the ordinary purpose.

The PRESIDENT. I have received a recent communication or suggestion which I think can be utilized by the members of this association; at any rate, I am anxious to impress it upon the members of the association. The suggestion is this: That the newspapers have been criticizing the local forecasts, and that we ought to seek opportunities to give the papers some important news. Say to the reporters, "I have got a little item here which will interest you and that will also be of interest to your paper and to your locality." Tell the reporters to call around occasionally; that you can give them something which will be of interest. If we do this the papers will certainly be more lenient in their criticism on the Bureau. Give them something that they consider of interest and value and that will benefit them to publish. Before we go any further on this subject, there is a gentleman here who has the honor of having first called a convention of State weather service men, Mr. J. B. Connor, of Indiana. He was the head of the State weather service thirteen years ago, and he conceived the idea of calling his voluntary observers together in convention. He is still interested in this work, and he is also the owner and publisher of the Indiana Farmer, which publishes the crop bulletin of this State, and which spreads information throughout this as well as neighboring States. I would like to have him give his views on the subject of voluntary service to this convention for a few moments.

Mr. J. B. **Connor** (Indiana). I have always been very much interested, as our president says, in the work of State weather services. It was at the instance of Governor Porter, of this State, that the service was organized in Indiana, when I was the chief of the bureau of statistics, and I believe our first convention was called in 1882. I had heard a great deal on the subject of the State weather service, but it was a new kind of work for me. To secure a respectable number of stations in the State, if you will permit me to go on with this suggestion, I prepared a circular and sent it out to the various people whose names I had obtained who were not in our work, and many expressed their willingness to take hold of the work, and it was in this way that the voluntary observers were secured. I was only connected with this service for two years, or perhaps less than two years, and as my successor as chief of the bureau of statistics seemed to have no appreciation of the work, it was afterwards transferred to the Agricultural College of the State, which was well fitted up, and from which the State is gaining very much advantage, for certainly the service has become very efficient and very valuable to the State. Well, it was in 1882, I think, that the first meteorological convention was held that was ever held in the United States. At that convention we secured the attendance of nearly all of the voluntary observers we had obtained, and the convention interested them very much. It was as a result of that kind of work that the interest was kept up in the weather service. I am glad to look you all in the face and to see so many States represented here. Certainly you are engaged in a very important and a very great work; but it is a work that is not fully appreciated as yet.

I heard some of the discussions this morning about retaining and securing voluntary observers. That is a very important question, and a question that the public does not yet have full appreciation of. We are all trying to live a year in a month. That is our trouble. We live too fast. We want to know it all from the start to finish at once, and we are trying to do a great deal more than we are able to do; yet a great deal of work is being done, and the data that has been collected by the State weather services all over the country will sometime, not many years hence, vindicate the splendid work you are doing.

Mr. **Jennings** (Kansas). In regard to this map of which Professor

Swezey has spoken, I want to say that it has cost me 60 cents a week all the season through. I, for one, want to thank Professor Swezey for the explanations he has given us. We started out with using a plate map; we first got the idea from Nebraska. The Kansas Farmer printed it, and it was a great success. We heard all through the season how that map was appreciated, but at the close of the season, when we stopped it, the Kansas Farmer people came to us and asked us if we were going to stop putting that map in the paper. They asked if we stopped the weekly reports, why couldn't we give them a monthly map. Now, they are going to publish a monthly map at their own expense, showing the distribution of the rainfall all over the State. The Kansas Farmer told us that they never dreamed that the subject had such a strong hold upon the people—upon their subscribers—until we cut off printing that map, and then the letters came pouring in. They are now going to publish a monthly map, which came out for the first time, I believe, in September. We can get perhaps 200 of these papers free, and distribute them over the State, and when they are in the hands of the various State weather service men we can increase the value of the weekly bulletin.

Mr. SAGE (Iowa). When rains are very local in character I do not see how it is possible, on such a small chart, to include the rainfall of places which are so close together. This is the fault I find with the method of illustrating by charts.

Dr. I. M. CLINE (Texas). Speaking about the people getting interested in the precipitation charts, I wish to say that we began the issue of these maps in colors in 1891. The value of anything is to be judged by the extent to which it is used by those interested. The demand for this chart became so great that the labor involved in the preparation of a sufficient number of them necessitated a change to some method which would require less labor. As an illustration of the practical value of these charts in Texas, a cotton factor in Galveston, who advances large sums of money each year on the crops of farmers in various parts of the State from time to time while the crop is making, says that he takes those charts and hangs them on the wall of his office, and whenever a planter wants money on his crop he can, by a look at the rain charts, determine just how much money it will be safe to advance on the crop. This is a single case; I could cite a number. Our people would not do without this chart. In order to enable me to issue the chalk-plate map it was necessary to obtain the assistance of the newspapers. When I first commenced the issue of the chart, as already stated, I could not convince them of its importance, but they eventually recognized its valuable features, and in last June the Galveston and Dallas Daily News, and also the Semi-Weekly News, which is issued on the day of issue of our bulletin, commenced the publication of the chart, which gives it a circulation of 100,000 on the day following its issue, and mostly in small villages and among farmers where it is of greatest value. The chart has already become such a prominent feature of the bulletin that every daily paper in the State desires to publish it. A paper of some 20,000 or 30,000 circulation, published 50 miles from Galveston, sent a man down to see me last Friday to see if arrangements could not be made which would enable them to publish the chart. I advised them that I would furnish them with a miniature map of Texas ready to draw from. We are at no expense for this chart except the labor in drawing it, which is contributed by myself or one of my assistants. The papers give us the base plates, make the casts, and get them ready for us.

Mr. **McGann** (New Jersey). I would like to ask the question whether it is considered the omission of the reports of crop correspondents would detract in any way from the value of the bulletin, or whether it is considered advisable to publish a bulletin, as a great many of the services do, without the notes from their correspondents?

Mr. **Sage** (Iowa). If I had my choice between the two—as between the bulletin that contained the reports condensed, as the correspondents gave them, or the one that contained the editorial summary—I would say leave out the summary every time. The people want reports that they can study as to their own and other localities. These inform them of the condition of crops in the agricultural districts, of the live stock and the diseases of live stock, and so on, and the people are continually looking for some reference to those things in the weekly bulletins. They want specific information and not mere generalities.

Mr. **McGann** (New Jersey). I have advocated at previous meetings the advisability of all weekly crop bulletins being published with reference to what the farmers themselves do and say relative to the crops. If you do not publish these items, then the weekly bulletin is of little value to them. Its great value is in what the farmers themselves say about the crops. This is so as far as my State is concerned. Of course I do not want to force any of my ideas upon you, because the interests of the different States are so diversified that what would suit one State might not suit another.

Mr. **Townsend** (Pennsylvania). I want to say just a word in regard to the illustration of weekly rainfall by map shading. I think it is misleading, particularly where the showers are local in character, as they generally are in my own State during the summer months. In connection with this subject, in giving the amount of rainfall I think we lose sight of one very important factor in failing to give the character of the rainfall, whether heavy or light. This is particularly important in hilly countries like Pennsylvania, where the light rains are absorbed by the soil while the heavy downpours run off rapidly to the adjacent streams. The duration of each rainfall should be reported.

Mr. **Hersey** (New Mexico). In regard to graphically illustrating rainfall, I do not think the plan well adapted to New Mexico for weekly reports, and for monthly reports it can be used to little advantage.

Frequently there will be no more than one or two stations reporting for a whole week, possibly only one station, and it would report from half to three-quarters of an inch—just local showers, it may be, and so it would really amount to nothing more than putting the figures on a blank map in many cases. I think it should be left to the directors of the different services what they should use and what they should not. I believe it is a good plan to use extracts from the reports of the voluntary observers in as nearly their own language as possible. The most of the weekly papers of New Mexico contain the remarks of the observers and their authority for their remarks. I believe this plan is of more interest to the public, and it also keeps up the interest of the observer in his work.

Mr. MITCHELL (Florida). Apropos of the rainfall relative to Florida, I feel sure that the chart would be misleading, and substantiate the theory by citing the case of two rainfall stations that I think are about a mile and a half apart. The voluntary observer obtains the official reports from the experimental station there, where the rainfall is kept. Now, it has been my observation during the past five or six months that within distances of a mile and a mile and a half there are many times 2 or 3 inches difference in the rainfall for these two places. My attention has been attracted to marked difference in stations closely located. During the summer months in Florida, sometimes it rains forty days and forty nights not half a mile from the coast; consequently, I think the insertion of the rainfall on blank maps at specified stations will meet all demands and will be more faithful to the exact meteorological conditions.

Mr. CHAFFEE (Alabama). Regardless of the question as to how the rainfall data should be published, on which there seems to be some diversity of opinion, and coming back to the question as to whether selected voluntary observers should not be given authority to telegraph State centers reports of rainfall, I would like to say in the interest of the cotton industry of Alabama, which is one of the greatest cotton growing States, that I am sure I could make good use of such telegraphic reports; they would enable me to issue more exact information as to rainfall throughout the State. I am sure such information would be very much appreciated in my section.

Mr. BATE (Tennessee). The character of the rains in our State is mostly very local. I have looked out of my window and seen a fine shower right across the river and not a drop of water in my rain gauge; and then, on the other hand, we have had showers at Nashville and the surrounding country has not had a drop. The best way I think is to use the figures.

Professor SWEZEY (Nebraska). That is very true, if you have a limited number of stations. As it is in Nebraska we could not begin to write those figures on these maps; they would cover the whole map, and of course if you were to put in the location of the rains every time it would be misleading; the maps would not hold that number of names, as you have but very little space.

The **President**. Mr. Berry has had a great deal of experience on the subject of rainfall and may possibly have something to say to us.

Mr. **Berry** (of the Weather Bureau). Mr. President, while admitting that any method of graphic illustration is open to objection, I still believe that the scale of shading adopted by the national Bureau for the Monthly Weather Review and Weather Crop Bulletin affords a very satisfactory means of exhibiting the distribution of rainfall. Precipitation measurements are generally recorded in inches and hundredths, and with any considerable number of reports the figures would appear so crowded on a map of small scale as to render it impossible to obtain at a glance an intelligent idea as to the general distribution of rainfall which can be so readily seen on shaded maps. The accuracy of the charts of course depends upon the number and reliability of reports and the competency of the person preparing the map. In our best books on meteorology and in current publications on that subject graphic illustrations are extensively employed, and I do not think that we can do better than to continue the use of shades for representing rainfall distribution.

Dr. **Hyatt** (Mississippi). While we have never published the rainfall chart of my State, I think it is important. The great objection is the expense connected with it. I have found in my experience that the publication of the remarks and names of correspondents has been of great benefit and interest, and I have noticed that the reports are rendered more promptly and more numerously than before on account of these publications.

Mr. **Mitchell** (Florida). With reference to the advisability of selected stations telegraphing rainfall for the weekly crop bulletin, it strikes me that this is a question deserving more than passing notice. Many stations in my State have to mail reports a little in advance, and subsequent to mailing it is not infrequent that a general and refreshing rain visits the county, and under such circumstances to use the data on the weekly card (which might indicate need of moisture) would be misleading and do harm. As it is, I keep close watch of press telegrams, and with the general weather conditions indicated on the chart am enabled to represent matters very satisfactorily. However, a few isolated though important stations could be selected to telegraph rainfall with much advantage.

The **President**. We will now proceed with the third subject, "Monthly publications."

Mr. **Chaffee** (Alabama). As to the best form of publication, which is an important subject, I wish to say that it was my idea to have a double sheet like that prepared at the office of the Bureau, and have them printed in great numbers. The cost would be but little. One page would be enough for all of the stations, with the headings printed in. I think that it is important that we should have something that we can preserve for reference if necessary. The two sheets can be bound together. I have used such sheets for some time, and they embrace everything that is found in the monthly reports. We ought to have these publications in some form in which we can preserve them.

Mr. **McGann** (New Jersey). It may be useful to some of the gentlemen here who did not attend the convention at Brooklyn last year to know something about the method discussed there relative to publications of the experimental stations. The director of the State experimental station of New York was asked to express his opinion relative to the value of publications that were being sent out by him in that State. He wrote to the secretary of the agricultural board that he thought so highly of the work that was being done that if the appropriation was increased they would carry it on. Now, it may be, as perhaps one of the gentlemen here said, that if there was an appropriation for this work more of us might undertake to publish the monthly bulletin.

Mr. J. I. **Widmeyer** (Oklahoma). We have also an experimental station in Oklahoma, which is located in the northern part of the Territory. The director of that station offered me $600 if I would move my station up to his place and prepare the meteorological data for them to print. I have always been sorry that I was not so situated that I could avail myself of the offer, because it would have been of great benefit to the Territory. Our publication is about the size of that used in Texas, and on the first page we have the names of the voluntary observers, which is used for the benefit of the observers themselves. We get their remarks as far as we can, but the chief feature of our bulletin is the manner in which the rainfall is presented. We have it so that we get it up in the shortest form possible, as we find this is the most convenient for reference. There are so many people coming in from day to day, and they all want to know the amount of rainfall. We publish this bulletin in Oklahoma without any cost to the national Bureau.

Dr. I. M. **Cline** (Texas). I think the bulletin we issue is about the uniform size, or standard size, for such publications, and contains the data most desired for file and reference, namely, the daily maximum and minimum temperatures and the daily precipitation. While our bulletin is printed, it is not impracticable for those who prepare their bulletins by some duplicating process to make them of the same dimensions (although they may contain different data if desired) so that the bulletins of the various State services can be bound together. The question of prompt issue of these bulletins is also another important one, and I think we should give much attention to it.

After Dr. Cline's remarks the convention adjourned until 10 a. m., October 17.

DISCUSSION AT THURSDAY MORNING SESSION.

The **President**. The convention will now come to order, and we will proceed with the fourth subject of our programme, "distribution of forecasts." The members of the association are at liberty to discuss any one of the heads given.

Mr. **Townsend** (Pennsylvania). This is a matter I have had under consideration for some time, because I believe the use of flags will be greatly improved upon; therefore I have submitted to this convention, in the simplest form in which it can be constructed, this semaphore, which I wish to explain. [The semaphore was here exhibited.]

The "Semaphore weather signal" consists of a weather vane and disc so connected by an arm that the disc can be revolved and retained in any desired position.

By it eight distinct combinations can be given that are determined by relative positions of the disc to the vane, and they are easily distinguished and understood, because they are suggestive of the weather conditions—higher, lower, stationary temperature, or a cold wave, with fair weather, rain, or snow.

As a combination signal its visibility is greater than that of flags, cones, or drums, because the element of position only is all that is necessary to determine to understand the combination.

It is distinctive in character, simple in construction, easy to manipulate, and not liable to get out of order.

In point of durability and economy it will outlast several sets of flags at a much less cost.

By the use of electric lights it can readily be made a night signal.

Question. What would be the cost of such an instrument?

Mr. **Townsend** (Pennsylvania). Well, that of course depends upon how it is constructed; but they can probably be made for about $2. It is so simple in construction that most anybody could make one with a little effort. I do not claim it is in any way superior or inferior to flags, but I think it has advantages that flags have not.

Mr. **Salisbury** (Washington). May I ask if the semaphore is supposed to assume a certain position, or if there is a mechanism for the purpose of revolving it horizontally?

Mr. **Townsend** (Pennsylvania). There is no mechanism for revolving it horizontally.

Mr. **Salisbury** (Washington). I do not wish to speak discouragingly of this design of semaphore, which has evidently taken much thought and has admirable points, but as I understand its construction I will say that I do not think it will accomplish the purpose of indicating weather signals as well as flags, for the following reasons: The semaphore is not well adapted for indicating signals to points directly before or behind it, as on railroads. When behind it the signal is reversed, which is a disadvantage. The plane of greatest visibility is at right angles to the plane of the semaphore, and the visibility decreases as the angle decreases, until at zero, or 180°, the signal becomes practically indistinguishable, as is the case with any flat object viewed on edge. This I regard as a fundamental objection. No, I do not think flags have this defect to the same degree. It is hard to choose a position from which either the form or the color of the flags can not be determined, no matter what the wind direction. I am not a defender of the flag system, but if a change is made it should be to something better.

Professor **MOORE** (Chief of Weather Bureau). I think Mr. Salisbury has stated a very serious objection to the semaphore.

Mr. **CHAFFEE** (Alabama). It seems to me the objection as to the visibility, or rather the invisibility, of the semaphore signal could be easily remedied by having the tail of the semaphore composed of two pieces of plank, to be spread out at the outer ends like the tail of a wind vane; then have a ball in place of a disc, as now shown; this ball could pass between the two pieces of the tail when moved above or below it; such an arrangement would make the signal thoroughly visible from all directions.

Mr. **MITCHELL** (Florida). I believe almost any change would be an improvement on the present system. Flags soon become soiled and worn, and after the lapse of, say a year, are unsightly. In the interior of Florida there are many days when the flags indicate nothing—not being seen, due to lack of wind.

Mr. **TOWNSEND** (Pennsylvania). Whatever may be the value of any work done by the Weather Bureau with the general public none ranks in importance with that of forecasting. This is daily demonstrated by the desire manifested to obtain the forecasts. Years of constant and well-directed effort has developed the present extensive system of distribution, which is highly creditable to the Bureau, but the limit has not been reached, and the experience of those engaged in State service work should enable them in replying to questions *b* and *c* of the programme to make practical suggestions in the line of improvement. I submit the following for consideration:

(*b*) Should flags be displayed to represent forecasts for the current day?

I answer, yes; but all displays should be so made that the public will know exactly what time is covered by the forecast. I find under the present system of display a lamentable lack of definiteness in their interpretation, and to remedy this defect I suggest that all displays from early morning to 1 p. m. shall be a forecast of the weather conditions for the current day, and all displays from 1 p. m. to dark shall be for the ensuing day.

(*c*) Can forecasts be given wider dissemination in rural districts, and what can be done to prove the value of forecasts in sections where they are not utilized?

Districts remote from mail and telegraphic facilities can only be reached by a concerted system of signal duplication. This is entirely practicable where the residents at proper distances from each other will erect and display signals similar to the one that should be copied. By properly organized efforts on the part of those who desire to avail themselves of the benefits to be derived from the daily information furnished by the Bureau, there is practically no limit to the territory that can be rapidly covered by information signals at a small cost and with very little labor.

Farmers should willingly bear a part of the voluntary service that is daily performed for their benefit, particularly when the information to be transmitted is of practical value to them and their neighbors located so remote from telegraphic and mail facilities that their district can not be reached with the desired information without their cooperation. To insure correct and prompt displays at the distributing center the display man at that point should be paid a small salary.

For such displays the semaphore signal is undoubtedly better than flags, because of its greater visibility and lack of dependence on strong winds for its proper exposure. Besides, when once constructed it should last a long time without sensible change and always be ready for immediate use. Its ease of manipulation enables almost anyone to make the necessary changes in the combinations.

In answer to the last paragraph in (*c*), a little experience will prove the value of the forecasts where they are not now utilized.

(*d*) Should not forecasts be telegraphed to daily papers of small cities to avoid use of obsolete forecasts given in plate matter used in make-up?

Yes. As daily papers are necessarily dependent on large subscription lists and good mail facitities for their support, it necessarily follows that they are among the best and cheapest means for the prompt dissemination of forecasts.

(*e*) Value of the logotype system.

This is an economical manner of distribution, and in most cases has been found satisfactory.

Professor HUSTON (Indiana). I think it is a matter of some importance to know for what purpose the forecasts are used. I was very much surprised to learn this summer that in Fayette County, this State, which is about 60 miles from here, there were extensive tobacco crops being raised which represented a high monetary value. I happened to be down there in the fall, and I asked a man who owned one of the large crops if they received any warnings or forecasts there, and he said no. I told him at that time that he had better get his tobacco in then as quickly as possible; and when later I was down there again I found that he had taken my advice, and that he had it all cut and in the house. I think we should use much care in finding out what new crops are being raised. I know of extensive pickle industries going up, and also many others recently coming in which are more than usually sensitive to unusual weather conditions, and I believe it is no small part of the business of the weather service to keep posted on these new things. Of course when a State is in the extreme north or the extreme south that it is not so easy, and can not so easily be kept track of; but the central part is where changes occur quite rapidly in the system of agriculture, and that of course means a change in the nature of the forecasts that are to be made for this section.

Mr. FRANK BURKE (Kentucky). In regard to the tobacco crop in our State, ordinarily we do not have a frost that will do any damage to it once in four or five years. The crops as a rule are nearly housed by the 15th of September; that can almost be depended upon. I think the damage that was reported this year was largely individual and not at all general; there may have been some certain localities where the crop, owing to unfavorable conditions, was set out late, and it was damaged. But I had reports from some reliable correspondents and voluntary observers saying that there was in their section of the State, southern half, not more than 5 per cent of damage to the tobacco, and I was also informed by the secretary of the tobacco board of trade that this was so, and his statements corroborated those of the correspondents. The last frost of September 30, which was very general, was forecasted in time to reach us, but unfortunately it reached us on Sunday morning. I succeeded in getting word to some of the stations, but most of the telegraphic stations were closed, and of course much damage was done. I do not think the conditions warranted the forecast being sent out on Sunday morning.

Mr. H. W. RICHARDSON (Ohio). In our State I knew pretty well that most of the crops had been cut and housed, and so it did not do much damage. I tried to reach some of the stations in the southern part of the State, and also in the vicinity of some of the northern counties, but I did not succeed very well.

Mr. HACKETT (Missouri). I wish to say a word with regard to the distribution of forecasts by the logotype system. I think that better service would result if the forecast messages sent to distributing displaymen were so worded, in all cases, that they could be exactly duplicated with the logotypes furnished them. Very few of the displaymen have time to write in words on the cards with pen or pencil, and when forecast telegrams contain words not included in the logotype vocabulary some try to change the wording of the forecast, while others omit a portion. As a rule, probably less than a dozen people see the original telegram, while the forecast as printed on the cards is read by thousands. The forecast official, or the official in charge of the station from which the forecast is telegraphed to the displayman, is better able to determine the words of the logotype vocabulary which will best convey the information contained in the forecast, and I think that in all cases the message sent to the displayman should be so worded that he will be able to duplicate it exactly.

Mr. LINNEY (Illinois). I have found very great difficulty in instructing the displaymen what flags to put up—whether for the day before or the day following. It seems to me that some better rule than we have at present should be adopted. The information that it is desired to give the people will be given to a great many more people by having the flags for to-morrow displayed instead of for to-day, but we have the trouble of not receiving our forecasts until about 12 o'clock. Another difficulty is insufficiency of words in the forecast vocabulary. Oftentimes the meaning of the forecasts when telegraphed are not clear on this account.

Mr. SALISBURY (Washington). The forecasts are often so worded that displaymen find it difficult to determine what flag or combination the forecaster desires or intends to be hoisted. I have encountered the same difficulty myself, and it is likely that displaymen with limited experience are more frequently unable to decide correctly or with certainty. I advise the addition of two words to the message containing the forecast which would designate exactly the flags desired hoisted. It might be done by one cipher word if a code were furnished the displayman. The additional cost would only be trifling; in most cases it would not add at all to the present cost.

Mr. BRONSON (North Dakota). Referring to the size of the card, it may be well to encourage any change tending to reduce its size. The cards are so large that they become torn and ragged in being tied together with other mail, and when they reach us present a very untidy appearance. I think they should be cut to the size of ordinary mail.

Mr. BATE (Tennessee). I do not think the cards are too large, and if they are torn it is through the carelessness of the postal officials. But I do think there should be some improvement in the quality of the paper used. They use paper now that is very easily torn and mutilated. I think the present style of card is very good for the purpose for which it is used, and is distinguished from the ordinary postal card.

Mr. MITCHELL (Florida). Regarding the card in current use, my attention was called to its abnormal size, when compared with the ordinary postal and letters, by the postal clerks, who explained that cards were cut by the tiestrings owing to the difference in size of the mail matter. The present cards, however, give good service.

Mr. CHAFFEE (Alabama). I have a suggestion to make relative to the question, "Can any improvement be made in the present system of forecast distribution?" I would suggest that through the cooperation of the Post-Office Department our weather forecasts might be printed on mail matter as a part of the postmark. My idea is, that postmasters be furnished some simple outfit with which they could stamp the weather forecasts as part of the receiving postmark on letters, etc., delivered through their offices. Right above the present postmark should appear the words, "Weather to-morrow," then the weather and temperature forecast expressed in two words, as "Fair, colder," "Rain, warmer," "Clear, cold wave," etc., these words to be made as logotypes which could be interchanged with little trouble.

This would entail no extra work on the postmasters, and to my mind, would secure an unprecedented distribution of weather forecasts and warnings. If the present weather signals of two flags convey information of any value, and they certainly do, then two words printed as suggested will convey even more. When we stop to consider the many million pieces of mail handled by the Post-Office Department—and while we could not expect to print our forecasts on all of them, if they can appear on even a part we will be doing much to familiarize the public with the Weather Bureau and to extend its benefits.

Mr. MITCHELL (Florida). In keeping with the ingenuity characteristic of the gentleman from Alabama, I think his suggestion a good one, and its adoption will be a significant medium in disseminating the daily forecasts.

Mr. Chaffee's suggestion was very favorably received, and provoked considerable discussion, Messrs. Huston, Hersey, Salisbury, Clark, McGann, Mitchell, Bate, Berry, Glenn, and Widmeyer participating therein.

On motion of Mr. Hersey, a committee, consisting of Messrs. Glenn, Townsend, and Chaffee, the latter as chairman, was appointed by the president to thoroughly investigate the practicability and benefits of Mr. Chaffee's suggestion, and to report to the president. The report of the committee will be found at the close of this pamphlet.

PROCEEDINGS AT THURSDAY AFTERNOON SESSION.

A number of the delegates desiring to leave on trains departing during the afternoon, it was decided not to undertake the discussion of the last two subjects, but to close the convention after the election of officers.

Mr. T. B. Jennings, in charge of the Kansas weather service, offered the following resolution:

Resolved, That in view of the fact that the Hon. J. Sterling Morton, Secretary of Agriculture, has not only faithfully stood by civil-service regulations, but has observed the true spirit of the law in filling such places in the national Weather Bureau as by reason of rank and salary were outside the pale of that law, and has even selected the head of the Service from the ranks of its practical workers, that the American Association of State Weather Services expresses its gratification, and recognizes the benefits which must accrue to the public service by applying such economical and business principles to the administration of a great weather service.

The PRESIDENT. Before submitting this resolution to a vote, I desire to express my hearty concurrence in the sentiments embodied therein. I wish to congratulate this association, the Weather Bureau, and the country at large upon the selection of the Chief of Bureau "from the ranks of its practical workers." We, as members of the American Association of State Weather Services, can appreciate the advantages that our organization will receive by placing one of our number at the head of the Weather Bureau, as our very existence depends upon hearty cooperation with the national Bureau. Our worthy Chief, having a thorough knowledge of the value of the State weather service work, can not fail to lend that aid and support so necessary to secure future success and usefulness. The employees of the Weather Bureau are to be congratulated, because this selection assures them that there is a future for every employee, and that attention to duty and efficiency are certain to lead to advancement. In my judgment, no better selection could have been made for this important position, and it will prove an object lesson to the workers in the Weather Bureau which can not but result in extending the usefulness of the service. Professor Moore owes his position to-day especially to his proficiency in forecast work, and this, coupled with the fact that he possesses that judgment, energy, and executive ability which enable him to widely disseminate forecasts and storm warnings of special importance when and where they would prove of greatest value. It was his excellent forecast work, combined with what I may call his efficient outside work, which attracted the attention of the public and the authorities and commended him for the position which he holds. The country at large is to be congratulated upon the selection of such a Chief, for the reason that the past record of Professor Moore is an indication that the importance of the practical as well as the technically scientific work will be especially emphasized during his administration, and I am confident that no opportunity will be lost to improve the forecast work of the Bureau and secure wider distribution of its information for the benefit of the public. I feel sure that this resolution will have the unanimous support of the convention. I hope to have opportunity to render Professor Moore loyal support in his efforts to increase the efficiency of the Weather Bureau.

The resolution offered by Mr. Jennings was unanimously adopted.

Mr. Bate (Tennessee) spoke in behalf of holding the meeting of 1896 in his State at Nashville, and in connection therewith presented the following communications:

STATE OF TENNESSEE, EXECUTIVE CHAMBER,
Nashville, October 14, 1895.

American Association of State Weather Services, Indianapolis, Ind.

GENTLEMEN: Permit me, on behalf of the State of Tennessee, to invite you to hold your next meeting in the city of Nashville. The State of Tennessee will celebrate the one hundredth anniversary of its admission into the Union by holding a grand exposition in the city of Nashville during the autumn of 1896. Our people are making elaborate preparations to receive and entertain all visiting associations, and it is the desire of the people of the State, expressed through me, that the members of your association give us the pleasure of your presence at some time during the continuance of the exposition.

Yours, very truly,
P. TURNEY, *Governor.*

OFFICE OF THE MAYOR,
Nashville, Tenn., October 1, 1895.

American Association of State Weather Services, Indianapolis, Ind.

GENTLEMEN: We take great pleasure in indorsing the invitation extended by the chamber of commerce to your honorable body to hold your next annual meeting in this city—our centennial year. We will see that you receive a most cordial, hearty greeting, and that your stay shall not only be pleasant but profitable to each of you individually.

Very respectfully,
GEORGE B. GUILD, *Mayor.*

Communications were also received through Mr. Bate from the president of the city council of Nashville, the chairman of the board of public works, the chairman of the chamber of commerce, and the director-general of the Tennessee Centennial Exposition. The success of the Indianapolis convention being largely attributable to the central location of Indianapolis, and Nashville possessing practically the same advantages, it was decided without opposition to hold the convention of 1896 in the latter city.

Upon motion, the following resolution was adopted:

Resolved, That a vote of thanks be tendered the Indianapolis Board of Trade for their warm welcome and magnificent entertainment of the members of the American Association of State Weather Services during its convention in their city October 16 to 17, 1895, which the members of the association will long cherish as the most marked attention yet paid them by any commercial body or other organization since the establishment of the association.

Resolved, That the secretary of this association be instructed to forward to the president of the Board of Trade of Indianapolis a copy of these resolutions.

Letters were received from many voluntary observers and others cooperating with State weather services, expressing regret that they were unable to attend the convention.

A number of interesting papers were also presented, and it is regretted that it will be impracticable to publish several possessing much merit. Those given at the end of this report will doubtless prove of much interest to all interested in State weather service work.

The following officers were elected to serve for the ensuing year: President, Maj. H. H. C. Dunwoody; first vice-president, Mr. H. C. Bate; second vice-president, Mr. F. H. Brandenburg; secretary, Mr. James Berry; executive committee, Messrs. E. A. Beals, I. M. Cline, and B. H. Bronson.

The election of officers concluded the work of the convention, which was adjourned to meet in Nashville, Tenn., in the autumn of 1896, the date to be determined by the president and executive committee.

BIOGRAPHICAL SKETCH OF INCREASE ALLEN LAPHAM.

By his daughter, Miss Julia A. Lapham.

Increase Allen Lapham, to whom the country is largely indebted for the establishment of the United States Weather Bureau, was from his earliest boyhood a lover and student of nature. He was one of a large family of children, and obliged from the early age of thirteen to contribute his share toward the support of the family. While working with his father (who was assistant engineer on the Schuylkill and Erie canals) at Lockport, Dr. Lapham collected his first fossils, which were the foundation of his fine collection that became the property of the State of Wisconsin in 1876, after his death, and was burned in Science Hall of the State University in 1884.

In 1827 the family moved to Shippingsport, Ky., and the son became a rodman on the Louisville and Portland Canal, with the understanding that he should attend the

Jefferson Seminary, then under the charge of Mann Butler, the historian, when his services were not required on the canal. Very soon the canal duties occupied all of his time, and all thoughts of school were given up.

It was one of the great disappointments of his life that he could not secure a college education. An occasional day at school was all the time that could be spared from the duty of earning his own living and assisting in maintaining the home. His only education was acquired by reading, observation, and a life-long correspondence with men like Silliman, Sullivant, Isaac Lea, Darlington, and Joseph Henry, who had become interested in him by the exchange of specimens from his Western home.

Dr. Lapham was a careful reader of all scientific books obtainable, and in 1827 became a subscriber and writer for Silliman's Journal.

On receiving his first article, written when only 16 years of age, Prof. Benjamin Silliman wrote: "It speaks well for your habit of observation, unusual in one so young. Time will (perhaps sooner than you realize) remove the difficulty of youth, and I trust you will improve year by year in everything wise and good and become a blessing to your fellow-men." Almost a prophecy, as he lived for others more than himself; was ever ready with kind sympathy for all.

A very voluminous correspondence was carried on between Dr. Lapham and an older brother, also an engineer, and interested in the sciences. Every walk to Louisville, or along the bank of the canal on his daily rounds, furnished matter for these letters; some new flower discovered, an unusual number or variety of birds, a rotten log turned over revealing a new shell, some Indian relics thrown out by the workmen making the canal excavation, or possibly a sketch of some improvement in locks or bridges, the plan for a railroad around the Falls, or an account of an excursion with Victor Audubon to collect specimens for his distinguished father.

The curiosity of these brothers was excited by the bowlders scattered over the country. Every locality in which they lived was explored and notes made to be discussed in following letters. Not being satisfied with the theory that an immense lake at one time covered the country, as there were no barriers to raise the water to the height necessary to cover the highest bowlders—nor yet with the idea that bowlders were created where found, or were thrown out by volcanoes or earthquakes, they formed theories of their own.

That meteorology and kindred subjects were of interest to him in these early years is shown by the frequent mention of the state of the weather in his diaries and letters, and comparisons with other years and places.

The temperature of the Ohio River, especially during the flood of 1828, was taken at the surface and below and compared with the temperature of the air.

The following table of Dr. Lapham's observations at Shippingsport was published in The Focus, a Louisville weekly paper, in 1827. Later, he kept and published each month a record of the thermometer; no copy of these records is in existence unless in some file of The Focus or the Louisville Public Advertiser for 1828–29:

	Fair days.	Variable days.	Cloudy days.
September 15–30, 1827	3	8	4
October, 1827	9	7	15
November, 1827	6	6	18
December, 1827	5	3	23

When Dr. Lapham arrived in Milwaukee, in 1836, he began a study covering the whole of his adopted State. In its climate he was specially interested as possessing some peculiar features arising from the topographical and geographical position of the State, occupying as it does a portion of the two great valleys of the continent—the Great Lakes and the Mississippi. This interest led to the publication of the map of Wisconsin with the isothermal lines.

As a member of the Milwaukee Lyceum, in early days, he was appointed meteorological observer, to note and report at the meetings each week the wind, the rain, and the temperature; and as a voluntary observer he continued this work until the organization of the meteorological work of the Signal Service, frequently in threatening weather taking hourly and half-hourly observations.

Dr. Lapham's interest in the effect of storms on Lake Michigan was soon aroused, and a list of disasters was prepared by him and Mr. F. Randall in January, 1842, for a report to the trustees of the town of Milwaukee on the commerce and navigation of Lake Michigan. The list extended from January, 1834, to January, 1842, and considering the small number of vessels on the lakes in those early times, was appalling—118 lives were lost, $1,052,450 worth of property destroyed, and 89 vessels more or less injured.

In 1848, as one of the faithful band of observers for the Smithsonian, working for the love of science and the good of his fellow-men, he suggested to Prof. Joseph Henry that much more satisfactory results might be obtained in securing elevations by simultaneous observations on standard instruments at the same level whenever possible, and also suggested that instruments be furnished the Milwaukee High School.

By means of observations taken every three hours during the month of August, 1849, Dr. Lapham discovered that there was a lunar tide on Lake Michigan. He published this fact in the Milwaukee Sentinel and Gazette of September 3, 1849.[1] Ten years later this discovery was verified by the self-registering tide gauge placed by Capt. George G. Meade, superintendent of United States lake survey, on the pier near the entrance to the Milwaukee harbor.

In 1850 Dr. Lapham prepared three memorials to be presented to the legislature of Wisconsin, one for the board of trade, Milwaukee, another for the State Medical Society, and a third for the State Agricultural Society, urging that an appropriation of at least $1,000 be made to purchase instruments and establish a regular system of meteorological observations throughout the State of Wisconsin to ascertain the laws which regulate and govern storms, and by this means prevent to some extent the great annual loss of life and property on the Great Lakes.

This memorial also claimed that the knowledge of such laws would be of use and interest to all classes of men, especially to the farmer. That Dr. Lapham considered such knowledge would be of use to the physician is proved by the fact that he prepared a memorial for the medical society.

This being before the days of the common use of the telegraph, the greatest hope was to secure a series of simultaneous observations for a number of years, and from this decide on the probabilities for the coming season.

The memorial reads: "To say that we may soon be able to predict the general character of the coming season with certainty may seem presumptuous, and yet it would be far less wonderful than many similar discoveries recently made. If the life of a single individual engaged in commerce on the lakes, or if one steamboat or sail vessel can be saved by this means, the State might be considered amply remunerated for the expense."

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[1] The discovery of the lunar tide here ascribed to Dr. Lapham was undoubtedly announced rather prematurely, but Dr. Lapham's early publication may have stimulated the Chief of Engineers to order an investigation of this subject by the officers in charge of the survey of the Great Lakes. The real lunar tide in Lake Michigan was found to be so small that it is obscured by the solar tide and by the influence of the winds, the rain, and the barometric changes. It required several years of continuous self-registration and a careful mathematical analysis to establish the existence and extent of the lunar tide that had been predicted by the theory of gravitation.—(Signed) C. Abbe.

This effort was unsuccessful, but from that time Dr. Lapham used his influence in every possible direction to make some attempt to prevent the fearful results of storms on the lakes, urging the legislature, boards of trade of different cities, transportation companies, and private individuals to make the experiment, which he was sure, from his knowledge of storms and of what had been done in predictions, would be a success, but without avail, frequently meeting with ridicule or pity that a man should be so "carried away with a hobby." Strong in his convictions, he worked on, further study confirming his faith, until after twenty years' waiting the Government was induced to take up the matter.[1]

Although not the originator of the idea that storms could be predicted, yet, as Prof. Joseph Henry, of the Smithsonian, truly says, in a letter dated February 3, 1876, "the action of Congress in securing the storm signal service was due to the immediate exertions of Dr. Increase Allen Lapham, through the Member of Congress from his district, Gen. H. E. Paine, in setting forth the advantages of the system in the commercial interests of the Great Lakes."

When the meteorological service was organized in connection with the Signal Corps of the Army, of which Gen. Albert J. Myer was the Chief, Dr. Lapham accepted the responsible position of assistant to the Chief. The conclusions he drew from the daily reports were telegraphed to Washington, and from there sent to the lake ports, as predictions.

Dr. Lapham ceased forecast work in December, 1870, and resigned this position when he was appointed State geologist of Wisconsin in 1873, but did not lose his interest in the work, frequently preparing lists of disasters, tables of the mean temperature of various places, etc., which were of great interest to the community.

Dr. Lapham was a local authority on all scientific subjects, and was often appealed to "from city, State, and country" for information which he alone could furnish. Those well acquainted with him had no less cause to admire his modest, unassuming manner than his profound learning. "Socially he was genial, affable, and hospitable," writes a friend; "scientifically he was laborious, patient, conscientious, and unpretentious. He toiled for science from a love of science, but with a thorough and intelligent comprehension of the great possibilities that lie in the field of research. There was no bidding for popular applause in anything he did; his modesty was extreme, and his unselfishness was manifest in the care he took to give due credit to all."

IMPORTANCE OF STATIC ELECTRICITY IN WEATHER BUREAU WORK.

By E. A. Beals, *Weather Bureau, in charge of Minnesota Weather Service.*

The Weather Bureau is engaged in two distinctive lines of work, which in one sense are widely divergent, while in another they are closely allied and interdependent. The first and foremost field, and the one upon which our Bureau chiefly depends for its popularity, is that of forecasting the weather, and this science is now but slightly further advanced than was astronomy in the hands of the Assyrians and Egyptians some four or five thousand years ago. In those early days successes in forecasting astronomical events did not greatly exceed the failures, although they were sufficiently accurate to maintain the masses in the belief that a vast amount of knowledge had been acquired by their learned men, who, in consequence, were highly esteemed.

To obtain the largest sphere of usefulness, we must bend all our energies to the attainment of the utmost efficiency in weather forecasting. As fast as improvements in this line are made just so fast will methods open up for disseminating such information most thoroughly and widely to the people, whether living in cities or in thinly settled communities.

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[1] In 1869 he cooperated heartily with the Observatory at Cincinnati by sending daily reports for the weather bulletin of the Chamber of Commerce, which, with its daily probabilities, was issued under the direction of Prof. Cleveland Abbe.—Willis L. Moore.

That other branch of work undertaken by the Weather Bureau, which in popularity almost equals that of forecasts, is the weekly weather crop bulletins, wherein we treat of crop growth as affected by the weather. We wish by furnishing information on these two lines to keep the public advised of how best to employ their forces so that weather conditions, instead of operating to cause losses, may, as far as possible, be profitably taken advantage of. Or, in those cases where losses are inevitable, we have in view to so inform, that the least possible harm can ensue. To be able to comprehensively treat these matters, upon which our energies are most strongly centered, it is very essential that every atmospheric component known to bear on the question be closely studied.

We have done this so far as temperature, pressure, rainfall, humidity, and sunshine are concerned, but there yet remains an element having in some subtle way a most powerful influence on crop growth, which in addition can also be used most efficiently as an aid in forecasting rain and perhaps wind. This element is the electrification of the atmosphere, and so far as I know has never been used by the Government weather forecasters or discussed in crop bulletins as to its bearing on plant growth.

It is the object of this paper to give a few facts showing the important part atmospheric electrification plays in connection with crop growth, and how valuable it might be in assisting the forecaster to improve rain predictions, especially in the Northwest, where so many storms pass from the northern Rocky Mountain district to the Great Lakes before producing any rainfall of consequence.

In treating of the subject of crop growth we are confined exclusively to the part weather exerts upon plants, and this factor is by far the most important one of all. Temperature, rainfall, and sunshine are usually given as the dominating causes of whatever results it may be necessary to chronicle each week. These elements undoubtedly enter most prominently into the case, but that of electricity is one that can not altogether be neglected, for recent researches, made almost exclusively by foreign scientists, show that by withdrawing this atmospheric component vegetation remained very backward as compared with that not interfered with.

On the other hand, experiments made in France have conclusively shown that by increasing the atmospheric electricity received by plants a most marked increase in both growth and yield will follow. Other experiments made in Europe tend to show static electricity to be a powerful factor in stimulating growth in wheat, barley, oats, hemp, potatoes, beans, leeks, tomatoes, beets, parsnips, raspberries, and strawberries, but did not act favorably on peas, carrots, turnips, cabbage, or tobacco. In some of these experiments the production of root crops were quadrupled, while other plants were doubled or tripled. No deterioration in quality resulted from increased growth caused by electricity, which is often the case where large yields are obtained be means of irrigation.

The invigoration of plant life by electricity also tends to show, especially in the case of vineyards and orchards, that they are better able to withstand insect ravages, and perhaps it will not be long before spraying will give away to an inexpensive treatment of electricity that will solve the problem of insect pests now occupying so prominent a part in agricultural economics. It is patent to the dullest observer how revivifying a smart shower of rain often is to our city lawns. These rains, which may give only a very small quantity of moisture, cause the grass to fairly spring from the ground. The lawns were previously abundantly watered by hose, but no great growth ensued until after one of these showers, when all nature seemed to undergo an almost immediate transformation into renewed vigor and healthfulness. Such rains must carry down with them a great deal of electricity from the upper atmosphere to so stimulate growth, for the water alone can not do it, as demonstrated by the fact that sometimes other and greater rains, or abundant sprinkling with the hose do not produce such effects. It has even been clearly proven that an electrification of seeds often accelerates germination and growth, through the life stage of the plant thus treated.

Our experiment stations are so occupied in the matter of educating the farmers into better methods of soil culture; how to overcome the ravages of insect pests; advising how to improve live stock through breeding and feeding; how to prevent disease in vegetation; providing better seeds, and in many other minor ways, that but little attention is given to the weather factor involved and still less to the part played by its component of electricity. Their neglect leaves the field open to the Weather Bureau, and it should promptly grapple with it, for it is a most promising field and properly within its province under the liberal management now controlling its destiny.

Intensified farming is the order of the day. The world's population is increasing with alarming rapidity, while our land area remains fixed. The problem confronting future generations and is not so far ahead as many people think, is how to raise sufficient to feed the growing multitudes. Therefore smaller farms and increased yields are the great desiderata. To meet this requirement what field is more promising than that of utilizing the electrification of the atmosphere, and where will you find a better medium to undertake its accomplishment than through the efforts of the Weather Bureau, with its corps of trained observers.

In 1871, Prof. I. A. Lapham, one of the prime movers in the organization of the national Weather Service, said in a report to the Chief of the Signal Corps, regarding the value of instrumental observations of atmospheric electricity, that if they were practical, "an additional certainty would be given to the daily conjectures of the 'probabilities' of the occurrence of storms." Observations of this nature were then not practicable, owing to the delicate nature of the instrument employed and on account of the personnel of the corps not being sufficiently well trained to look after them. Twenty-four years ago the importance of applying changes in electrical potential as an aid in forecasting were fully recognized, but not then considered practicable for reasons that now no longer exist.

The value of our work has become a fixed necessity. The public demand that we give them the very best service that money will buy, and they are willing to pay for it; therefore the matter of cost of delicate instruments which even to a very small degree operate to improve forecasts need not prevent their use, and it can no longer be said that the personnel of the Service is not sufficiently well trained to care for them.

We know that almost always rain is preceded from 2 to 24 hours or more by a change in electrical potential, and that during rainy weather a change from negative to positive electrification is an equally certain sign that it will soon clear up. With this knowledge, how is it possible to longer neglect the application of this factor in our daily work of forecasting weather changes, and at the same time publicly maintain that our forecasts are the best that it is possible to issue. I believe when we have as much statistical information regarding atmospheric or static electricity as we have regarding the least studied of other elements now receiving attention in our daily reports, that we will be in possession of knowledge the application of which will not only wonderfully improve our forecasts but will materially increase the value of our crop reports.

We should be able to state in the latter that the corn during the week has received deficient sunshine, the absence of which, however, was not harmful, owing to a preponderance of electricity of the proper sign, positive or negative; and the lack of moisture experienced has as yet done no injury, owing to the temperature being slightly less than the normal. These four elements are the dominating influences connected with plant growth, and should always be mentioned in our reports if we wish to truly chronicle the effect of weather on vegetation.

There is much more that could be said in favor of our Bureau taking up this question of atmospheric electrification with a view to its practical application in weather forecasts and crop reports. Its bearing in the new field of sanitary climatology is of equal importance, and in that other great realm of psychology, which as yet is only just opened to our view, it plays a most important part. In answer, therefore, to the sixth topic of discussion at the fourth annual convention of the American Association of State Weather Services, I would suggest that this question of atmospheric electricity be the one whereby special investigation can be undertaken by both the State and national weather services with best results.

MINNEAPOLIS, MINN., *October 13, 1895.*

HOW BEST TO SECURE AND RETAIN THE SERVICES OF VOLUNTARY OBSERVERS.

By Mrs. L. H. GREENEWALD, *Voluntary Observer, York, Pa.*

The bone and sinew of each respective State service and its life's vitality are found at the central office. But the germs of its extended growth abide with the individual local observer, and the development of his respective station will impress that community favorably or otherwise with the value of the State service, and its best work as a whole may be overlooked and unappreciated on account of unfavorable presentment by the local observer.

The retention of the voluntary observer appears to be the gist of the question, though the reply embodies a reversal of the subject under discussion.

First, his interest in the work must be secured. Promptness and accuracy are indispensable in the daily work of observations. Without these, inaccuracies will creep in that will eventually render the record of that station valueless, and especially so locally. To meet these demands requires frequent denials on the part of the local observer of which the central office or the public at large can have no adequate appreciation. Especially is this the case where the observer is so situated that a substitute can not be depended upon to take observations during the absence of the regular observer when fulfilling engagements of profit or pleasure.

The summing up of a few figures in the State bulletins at the close of the month seems a poor return for the expenditure of time, and often labor, in producing the result. A greater showing of the work of the respective stations in the State reports and the results secured in the departures locally in temperature and rainfall of the working stations would be a great stimulus to advance and further that work locally and draw the attention of the local press, to whom the reports are contributed, to the advancement of the service and its accomplishment of a work that really in a great sense is of a greater local benefit than its dissemination as a sum total over wider districts. Naturally, the reference to local conditions would interest each respective newspaper and draw especial attention and comment to the local station, whose observer, either through want of time, influence, or excessive modesty, failed to make a personal presentment of local conditions. Newspaper reporters following in this marked-out track would naturally interrogate the local observer, and the State service would thus assume proportions previously unthought of.

The State service is generally looked upon as an auxiliary to the United States Bureau. But is not the blending of the reports in the State summaries a discouragement to the voluntary observer?

Admitting that the United States Department is more scientific, of longer duration, and reasonably, as a whole, more accurate in general summaries, their blending places the work of the State service in the shade and depreciates the work of the voluntary observer in the minds of the public as a factor that has not sufficient stamen to exist without the support of the United States Department. Let the reports be included in the same bulletin, but under other headings and separate;

and though a greater work in arrangement would devolve upon the director at the central office, the increased interest on the part of the voluntary observer would eventually make adequate amends.

If there must be a rivalry for the stimulus of greater scientific efforts, let it be between the stations of each respective State service and a special feature made of the work of the best managed stations. This would arouse ambition among the voluntary observers to secure increased mention by better and wider work. The State service is, presumably, not scientific. Rather is it a patient record of daily weather events, that when properly arranged and tabulated becomes a most valuable history of meteorological conditions in each locality thus represented, and as an official record will become a valuable historical adjunct for the section represented, and thus secure a local status for the voluntary observers if understandingly presented to the public through the local press. This is the "keystone of the whole arch"—local work. Each year increases its value and secures an influence that must become legislative and eventually set aside the extended opposition to State weather service appropriations.

The return for the voluntary observers' work other than the local status to which their individual work entitles them, are the publications of the United States Department. No praise is too great for their scientific value, but they fail to interest the voluntary observer because they are too scientific. The voluntary observer, generally speaking, must be educated up to the first and early principles of the work he is expected to perform, and the future of the State services depend upon these means. The dissemination of the bulletins of the various State services cannot be too highly spoken of, and acknowledgment is made with thanks to the Oregon State weather service, B. S. Pague, director, and also to the Michigan weather service, C. F. Schneider, director. Especial mention is made of the latter in the August bulletin (vol. 10, No. 9), which contains many ideas of great benefit to any one interested in climatology. Independent of the August review and compilation of September weather, the dissertation on "Protection from frost" is of particular interest, and was issued at a most opportune time. Let this line of work become an object to interest the voluntary observer over all districts wherever the bulletins are forwarded.

Each director, judging as to the needs of his respective district, should bring forward those needs in simple language. The distribution of the bulletins will meet individual observers glad to be informed upon points of which they feel their ignorance. Let simple instructions be given from time to time involving in simple terms the whole work of the service, the manner of securing the normal of barometric readings and their application, also of temperature and rainfall record and the keeping of the departure from the normal of the respective stations, using the most simple terms, and figures fully carried out for the dropping or continuing of fractions in their balances, and reducing to whole numbers, etc. Simple instructions in cloud readings, their growth, overflow, etc., would be of inestimable value in securing interest and keeping it. The very simplicity of these matters have probably caused them to be overlooked as a need. But there are, doubtless, intelligent observers who are ready for and capable of efficient work, who have never known or who have forgotten simple methods for securing a result, and whose pride would forbid its acknowledgment to the director of the central station, and causes the return of imperfect and unfinished work not so much from lack of inclination as of instruction.

Filling this need of what is required to retain the voluntary observers answers the question of how to obtain them. The wider dissemination of the work and the simplicity of its explanation will enlist the interest of others and cause a constantly growing desire to add to local status, if no other motive presents, by joining the ranks of the voluntary observers. But to stations in full working order, the greatest need to those which are established locally and issue weather bulletins and report to the local press, is a large blank card, franked and directed to the respective newspapers, who are glad to issue these climatological conditions. The expense of a well-managed station, when kept before the public, is an item the aggregate of which is surprising to the uninformed.

STATE WEATHER SERVICES: THEIR IMPORTANCE AND EQUIPMENT.

By A. J. MITCHELL, *Observer in Charge, Florida Weather Service.*

It is essential that methods should be adopted whereby the human family may enjoy all possible immunity from unfriendly weather changes and receive the benefit of those climatic elements which insure happiness and the prolongation of human life.

To those familiar with the facts it is superfluous to say that State weather services can be made indispensable auxiliaries in carrying out the plans of the national Service. Properly organized, with a corps of intelligent, zealous, and interested observers, there is no superior or more effective medium of reaching the public than through the instrumentality of these services. Primarily, it behooves every director to exercise more than ordinary care in the selection of observers. An observer may be ever so faithful, yet if his primary education is deficient his faithfulness is not always sufficient to offset the lack of ability.

Promptness is a cardinal virtue in meteorological work, and without it, is a case of "love's labors lost." It is too frequently the case that necessity or expediency dictates an appointment wholly unfit for the duties of an observer, resulting in unsatisfactory and worthless work. It is better to have no record than to accumulate data based upon observations incorrectly taken and the use of instruments little superior to the 10-cent thermometer of commerce. In the course of time State normals will be deduced from these records, and a false premise always leads to erroneous conclusions. Speaking more directly on the importance of State weather services, it is patent that only through this medium can local climatic features be established and the benefits to certain products arising from the proximity of sundry bodies of water and other surroundings fully appreciated.

During the past winter we had striking instances of this citation, for you may be aware that occasionally an icy blast reaches the peninsular region of Florida. However, there were sections where the ill effects of frosts were not felt, and some of our friends in the "land of flowers" could not refrain from the propriety of giving the cognomen "Frost proof" to a favored section, and we are here reminded that a frost-proof region in the times of blizzards is no less appreciated than a bombproof locality when the clash of arms is imminent. State weather service data give authentic information regarding seasonal, excessive, and annual precipitation, so important to engineers in regulating the depths of canals and perfecting systems of drainage, both highly essential in the agricultural and hygienic world. State weather service reports are frequently consulted by engineers engaged in the construction of expensive structures regarding the excessive hourly falls of pecipitation. This information is of no little importance in determining the size of conduits for carrying off excessive volumes of water. A recent application for the above information, where the value of the building was quite $500,000, attracted attention.

The wise and skillful physician no longer relies on the materia medica as the last resort of the healing art; on the contrary, he consults the meteorological data of the various States, compiled by the national Bureau. From this fruitful source can be largely gleaned the necessary temperature data, particularly the daily, monthly, and annual means, extremes, ranges, prevailing winds, and precipitation, not to mention the number of clear and cloudy days. This information, tabulated and in an acceptable form, thanks to State weather services, can be given for almost every village throughout the country. We know that the climate of different sections of almost every State differs, being largely influenced by surrounding conditions; and by climate we mean the temperature, cloudiness, precipitation, winds, and other meteorological features. For instance, Florida has both a marine and continental climate. Continental is used advisedly and in a comparative sense. The lower peninsular region, bathed by ocean and gulf, never loses its verdant freshness, while the northern section of the State early succumbs to biting frosts. In computing the mean temperature of the State and studying the adaptability of sections therein to the growth and development of certain products, it is advisable to divide the State into subdivisions, and consider the proximity of gulf and ocean, lakes and rivers, that we may know what part they play in our immunity from frosts and chilling winds. This information can be gotten with exactness from State weather service records only. In keeping with a spirit of progress, voluntary observers should be utilized in perfecting a more satisfactory record of thunder storms, and telegraphing to centers the occurrence of local disturbances, especially when the latter play an important part in the weekly data for crop reports.

As previously asserted, the data compiled by voluntary observers enable interested parties to decide the adaptability of sections and counties to the growth of agricultural and horticultural plants. While this information can be given, approximately, by referring to stations of the national service, it is more minutely and satisfactorily compiled from the records of voluntary observers. From the same source landed corporations, in setting forth the unrivaled attractions of their holdings, are not slow to grasp the situation, and as their "leader" point with unerring regularity and confidence to the climate of their State. A section of Florida was once questionably advertised as the only perfect thing under the sun. This, however, was before the freeze. The State immigration agent with grip well stored with literature, or, more properly, advertising matter of the recourse of the State, faileth not in being replete with weather statistics, not only of the State but of each county therein. The possession of such voluminous matter and local official data has been made possible by the generous cooperation of voluntary observers. The village physician, though isolated from scientific centers, has recourse to the records of voluntary observers, from which he is enabled to study the effects of local climate on prevailing diseases. It is well known that the health of a town or city, especially over inland sections, can be fairly measured or is materially affected by certain winds. This fact is so strongly recognized in Florida that the inhabitants along the eastern section, or more properly the Indian River country, have honored the southeast breeze with the professional title "doctor," and their doctor is an antidote for the malaria of the interior. With the local meteorological record the physician can chart the various diseases, the latter fluctuating with the excess or decrease of moisture and the rise and fall of thermal conditions.

The collateral information promulgated by State weather service publications surpasses in importance all publications of the Bureau, and is no mean competitor, in point of general value, to the daily forecast. To the army of unselfish, interested, and faithful crop correspondents too much praise can not be given, and we are not far wrong when they are styled the "right arm of State weather work." To them is due the successful effort of laying before each interested inhabitant, hamlet, town, city, county, and State the exact condition of every crop in every county in every State once each week. This information is largely disseminated by the daily press, and, posted as it is in many public places, presents to the public invaluable crop statistics. To whom, in particular, is such information valuable? Valuable to the merchant, who advances supplies and whose reimbursement is dependent upon a successful crop; valuable to the farmer, apprising him of the progress and condition of crops similar to his in adjoining counties and States; valuable to the nation, as through this medium all classes receive information; valuable to labor, by the sweat of whose brow all products come forth, and whose countenance is wreathed with smiles at Heaven's benignant gift, a plenteous harvest; valuable to transportation companies, by which they judge prospective traffic; and, lastly, valuable to the speculator, by whose unrighteous deals a "long" crop is made "short" and a "short" one "long."

If there are vulnerable points in State weather service work, it is to be found in the lack of uniformity of instruments used and the exposure of the same, and until these are corrected the observations will not bear that scrutiny desirable and necessary in official records. The remedy lies in the equipment of all stations with standard registering instruments; and why? Because it is not always convenient for voluntary observers using the dry thermometer to take observations on time, making it possible for serious errors to creep into the work. A passing thunder shower frequently calls the energetic, live, and progressive farmer to the field, else he may lose valuable hay, fodder, or other products easily damaged by moisture.

The next suggestion requiring attention is the exposure of instruments, and it may not be inappropriate to relate the following incident, confirmatory of the above assertion. A prominent and faithful observer of a near-by State, on being interrogated regarding the exposure of his instruments, made the following reply: "In the summer I expose the instruments from the south side of my house to get the greatest amount of heat; in the winter time they are exposed from the north side of the house to get the greatest amount of cold."

To perfect the system the "cotton region" instrument shelter should be adopted; and with an occasional visit from the director to inspect and come in personal contact with observers, making known the value of their reports and the appreciation of them by the Bureau, State weather services will have taken a long step in the direction of usefulness, and merit enhanced appreciation of public confidence.

HISTORY OF THE SOUTHERN CALIFORNIA WEATHER CROP BULLETIN.

By GEORGE E. FRANKLIN, *Observer, Weather Bureau.*

During the crop season of 1890 Mr. James A. Barwick, then in charge of the station at Sacramento, Cal., inaugurated the publication of a weekly weather crop bulletin, based upon reports received from the entire State of California. After a season's trial the system of publishing a bulletin for the State in its entirety was found inconvenient and impracticable, owing to the immense territory embraced in the State, which prevented the reports from southern California reaching the director in sufficient time to be incorporated in the weekly telegrams to the office of the Chief of the Bureau for the national weather crop bulletin. Therefore it was decided to have the weekly reports from the correspondents in southern California mailed to the observer in charge of the Los Angeles station, where they were to be summarized, and a synopsis of the information in regard to the condition of the crops and weather telegraphed to the director of the State service, by which means the desired information would be available for publication in the State bulletin and for communication by telegraph to the authorities at Washington for use in the national bulletin, and where a bulletin for the southern portion of the State could be published. As early as practicable after receiving authority to commence this work and the necessary instructions in relation thereto, the writer of this paper placed the subject before the people through the press and by correspondence with representative citizens of the various agricultural and fruit-raising districts, and by their aid and hearty assistance obtained correspondents from the principal places, and on March 21, 1890, the initial number of the southern California weather crop bulletin was issued. It soon passed the experimental stage and became an established feature of the Bureau's work at this station.

In the beginning some little difficulty was experienced in carrying out the scope and intent of this work, owing to the fact that the people were not familiar with its design; but, as the project unfolded and the information contained in the bulletins was laid before the public by means of free distribution of the publication in conspicuous places, and through the aid of the press in publishing the reports in detail, and by "news notes" and comment, the people soon saw the benefits to be derived from authentic and unbiased reports of the crops and climatic condition of the country, and readily assisted in the endeavor to make the publication a success.

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The southern California weather crop bulletin has been published continuously from its inception, and, owing to the peculiar climatic conditions of this favored land, the issue has been for each week in the year; the winter edition, or rather its calendar equivalent, receiving more attention from the public and being more highly appreciated than those of other periods. These months are in this section a season of active growth of all products of the soil and the time of harvesting of the citrus fruits.

With reference to the issuance of bulletins during the winter months as well as during other periods of the year, I desire to submit to your attention the following statement, which shows that fruits ripen all the year round; and this, in connection with the fact that the winter months, or the rainy season, is a period of active farm work—a period where east of the mountains nature is dormant and farm work impossible—fully justifies, I think, the time and labor expended on the publication; this is amply shown by its popularity and the steadily increasing demand for wider and fuller meteorological information.

Fruits ripen as follows: Oranges, all the year; lemons, all the year; limes, all the year; figs, July to Christmas; almonds, October; apples, July to November; pears, July to November; grapes, July to December; peaches, June to Christmas; apricots, June to September; plums and prunes, June to September; Japanese persimmons, November and December; guavas, nearly all the year; loquats, May and June; strawberries, nearly all the year; raspberries, June to January; blackberries, June to September; currants, May and June; watermelons, July to December; mulberries, July to December; nectarines, August; olives, December and January; pomegranates, September and December; quinces, October to December.

As an instance of the esteem in which the southern California weather crop bulletin is held, I desire to state that the Los Angeles Chamber of Commerce, probably one of the, if not the most public-spirited, and on account of the free exhibition of southern California's products in its halls the most unique institution in the United States, published at its expense, in cooperation with the Weather Bureau, the bulletin in a neat and attractively printed form during the winter for several seasons.

While the southern California weather crop bulletin has become an established and in many respects a successful publication, yet there are features which militate against its continued success; and among these is the difficulty of retaining reliable and competent correspondents, and the laborious and unsightly milliograph process of issuing the publication, especially during the warm months. The present system of furnishing copies of the bulletins and such other publications authorized by the Chief of the Bureau does not work well, as in many cases correspondents after sending in a few reports give up the task because of the, to them, inadequate compensation in return for services; and further, from the fact that the character of the information furnished is very much curtailed in the bulletins. The writer of this article is of the opinion, based upon experience, that if a plan can be devised of establishing an organized force of correspondents who could be displaymen, or otherwise agents of the Weather Bureau, at a small monetary compensation, a tangible and direct hold could be obtained whereby a sufficient number of correspondents could be secured, so that creditable publications could be issued. Perhaps this could be done by means similar to those employed during the cotton season, when reports are received of the temperature and precipitation at State centers. In regard to the milliograph process, while the work is as legible and neat as the process will permit, the bulletins should be printed, and the writer thinks in a uniform style throughout the service.

DISCUSSION.

The following remarks on several subjects in the official programme were submitted by Mr. C. F. von Herrmann, observer, Weather Bureau, and assistant director North Carolina weather service, Raleigh, N. C. Mr. von Herrmann did not attend the convention:

1. HOW BEST TO SECURE AND RETAIN THE SERVICES OF VOLUNTARY OBSERVERS.

In North Carolina the larger number of our voluntary observers are professors at the various colleges in the State, or physicians, who are more interested in the work of the State weather service and better understand its requirements than any other class. The increased amount of time devoted to meteorology in the schools, and the interest evinced by the medical fraternity in sanitary climatology is evidence of this fact. New observers at selected places are obtained by personal correspondence with prominent persons of that class, and an explanation of the aims of the service rarely fails to enlist interest in our work. Printed circulars indiscriminately distributed asking for volunteers have never been of much use. No inducements are offered beyond the usual promise that observers shall receive the publications of the national and State services. In my State all voluntary observers, displaymen, and crop correspondents also receive copies of the bulletins of the North Carolina experiment station, with which the weather service is connected; and as such publications are often very interesting and valuable, it is suggested that in other States where there may be no cooperation with the State experiment station the bulletins of the latter could probably be obtained for voluntary observers on request.

I think there will be no difficulty in retaining the services of voluntary observers if they are made to see that their work is properly valued and appreciated by the directors. At this station the courtesy is never omitted of a prompt acknowledgment by letter of the receipt of each voluntary observer's monthly report, and I would suggest the advisability of the issue of a postal card form for that purpose by the Weather Bureau. The occasional visit of a regular inspector would often renew the flagging zeal of many voluntary observers, by affording an opportunity for conversation and an interchange of ideas on meteorological topics.

It is undisputed, however, that no more patriotic class of citizens exists than the voluntary observers throughout the United States. Many have kept up their labors faithfully for long periods, and without their assistance the work of the State weather services would be impossible. I move, therefore, that the convention pass a suitable resolution in recognition of the value of the work of voluntary observers, and expressing the appreciation of the directors of State weather services in their cooperation.

2. IMPROVEMENT AND DISTRIBUTION OF CROP BULLETINS.

Most of the crop bulletins now published are admirable. The chief improvement which might be suggested is the addition of a rainfall and temperature chart. Unless, however, such charts can be as neatly reproduced as those contained in that model publication of the kind, the national crop bulletin, I do not advocate their use. Some of the rainfall charts now published in State bulletins are neither elegant nor edifying. In my opinion, a selection of the remarks of crop correspondents should always be printed, and rather than be omitted the general summary should be curtailed. There is a possibility of making the crop summary too long and too minute in detail, defeating the main object of the bulletin, and making newspapers reluctant to reprint it.

Before any additional labor is imposed in the preparation of the crop bulletin by possible improvements, it must be remembered that these bulletins are generally very rapidly prepared. Their value depends to a great extent on the promptness of issue. In North Carolina the crop bulletin appears on Monday, which has been found to be the best day. The preparation begins early in the morning, the copy is in the hands of the printer by noon, and the entire edition of 1,800 copies is mailed by 6 p. m. During the five hours limited to preparation from two to four hundred crop reports must be read and considered. At Raleigh we have neither the time nor the facilities for the preparation of rainfall charts.

I believe that it would increase the value of the crop bulletins to publish rainfall reports from a larger number of stations, and a supply of, say 50, rain gauges might be issued to each State by the Weather Bureau for the use of selected crop correspondents.

Formerly a detailed map of the State, in colors, was printed on the back of the North Carolina crop bulletin, and was considered an advantageous feature, but the expense was found to be too great.

Form No. 1053, meteorological, used by crop correspondents in forwarding their reports is perfectly satisfactory. Form No. 1054, request for special information, should also be in the shape of a postal card, which would make it easier to handle and lead State weather service officials to use it more frequently. A far better plan of collecting data from crop correspondents would be to establish subordinate collecting centers, say at each county seat. Let the crop correspondent at the county seat receive reports from subcorrespondents throughout the county, summarize them, and mail his county summary to the central office. In most cases all the county summaries could probably be printed in the crop bulletin. In North Carolina under this system there would be only 96 county reports to consider instead of several hundred individual crop reports.

The best form for the publication of the crop bulletin has naturally been selected by most States, a single page, with first a general summary of the weather crop conditions for the State, then for the different districts, followed by a selection of the remarks of special crop correspondents.

The public press will always furnish the best means for distributing the information contained in crop bulletins. Although the edition of the North Carolina bulletin numbers only 1,800 copies, it reaches at least from 20,000 to 30,000 readers through the daily and weekly newspapers, of which 65 reprint the bulletin in whole or in part. Copies are also sent to 365 post-offices, where they are displayed on suitable bulletin boards for the benefit of the public.

Nothing proves more conclusively the value of the weather crop information published by the State weather services than the steadily increasing demand for these bulletins. The disinterested source from which the information emanates vouches for its accuracy. Outside misrepresentation of crop conditions becomes impossible. The information concerning the current condition of crops is alike valuable to agricultural and commercial interests. It places farmers on an equal footing with dealers who purchase their products, by enabling them to estimate probable yields and to judge whether they are receiving fair prices for what they have to sell. Boards of trade, boards of agriculture, chambers of commerce, and similar bodies all find the information contained in the crop reports of the greatest value.

3. MONTHLY PUBLICATIONS OF STATE WEATHER SERVICES.

I cordially approve of the form of publication adopted by some of the best State weather services, in which an endeavor is made to make the monthly reports of interest to other than specialists by including popular articles on topics related to meteorology and climatology. The Iowa report is a notable example. But I am decidedly opposed to advertisements of any kind appearing in official publications. I have observed advertisements in weather service bulletins which, to say the least, were in very bad taste, and tended to lessen the dignity of the scientific work in which we are engaged. In those cases where the issue of the monthly bulletins can not be secured in a satisfactory form without the assistance of funds obtained from advertisements, the reports should be printed by the national Bureau, as suggested by Mr. F. P. Chaffee.

The monthly publications of the North Carolina weather service naturally take the form of the bulletins of the experiment station, of which the weather service is considered a division.

Promptness of publication is very necessary, as tending to keep up the interest of voluntary observers, besides making the information available to the public as soon as possible. Monthly reports should not be delayed beyond the 15th at the latest.

Uniformity in style of publication, though it might be desirable, is probably not practicable. I think it would be a good plan, as adopted by the North Carolina service, to bind up with the annual report the twelve monthly bulletins for the year, so that one volume will contain all the known data for the year.

With reference to the preservation in convenient form of the most important data from voluntary observers' records, I would suggest that the Weather Bureau issue record books like that which has been employed for many years by this service. A volume large enough to contain records from all stations for five years is used. Each page, large enough for twelve reports from two stations, is ruled on one side with columns for pressure, temperature, rainfall, wind, weather, etc., and on the other with spaces for entering miscellaneous phenomena, such as dates of thunderstorms, frosts, etc., and remarks by voluntary observers. All the known meteorological data for any station are thus conveniently arranged for reference. The reports of voluntary observers, after the sums and means have been verified, are first entered into this record book, from which the monthly bulletin is afterwards made up. A sample page of the book is inclosed.

4. DISTRIBUTION OF FORECASTS, VALUE OF LOGOTYPE SYSTEM, ETC.

The return to the method of telegraphing forecasts daily to displaymen instead of conditionally is unquestionably a great improvement, has renewed the interest of displaymen and increased the demand for the forecasts. The flags will be more promptly and carefully displayed. I am of the opinion that the display of the weather-signal flags in the cities is unsatisfactory and not worth the cost of the flags. People prefer to read the weather summary and forecast, and generally consult the nearest map for that purpose. The flags should be displayed only for a short time in the afternoon of one day to indicate the weather for the next day, and should be lowered about sunset. The display of flag signals may still be useful in the country, though eventually the wide distribution of card forecasts by mail should entirely displace it.

The logotype system of distributing forecasts I consider highly satisfactory and destined to supplant all other modes of disseminating weather forecasts until the telephone comes into more extended use. I think, however, it is better to secure the cooperation of postmasters rather than displaymen, and recent endeavors in that line in North Carolina have been very successful.

In view of the ever growing wider dissemination of weather forecasts is it not important that the people should properly understand the nature and use of the forecasts and how to estimate their worth? Although meteorology has developed rapidly during the past thirty years, especially in the line of weather forecasting, knowledge of the subject has not spread among the masses of the people in proportion to its importance in the everyday affairs of life. It is not generally understood that all the manifold and apparently capricious changes in the weather follow definite laws. Too many people still place reliance on the weather data contained in almanacs, on local weather proverbs of no real value, and upon the humbug predictions for months in advance made by certain notorious impostors in this country and in Canada, whose statements are based upon supposed influences of the stars, and are purposely worded so obscurely that they may be considered verified by any kind of weather. Surely, by this time it ought to be well known that none of the heavenly bodies have a perceptible influence on the weather, that there are no equinoxial storms, and that it is not necessary to wait for the wane of the moon before planting.

If the Weather Bureau is to reach the full measure of its value to the people the erroneous ideas still prevailing, especially among our farming population, must be eradicated. There is great need of popular information on the subject. The daily weather maps have been extremely useful in this line, but I will venture to say that many who receive the map do not understand it. I remember hearing a very intelligent gentleman remark, pointing to a long curved isobar on the weather map, "What a strange way for the wind to blow."

In my opinion, nothing would more increase the interests of the people in the weather forecasts and prove their value than the publication by the Weather Bureau of a popular bulletin on the subject: "How weather forecasts are made, and how they may be utilized."

The subject should be presented in a nontechnical style, and could be made very interesting. It should contain an explanation of the elements of meteorology, and a brief description of the instruments in common use. The operations of the Weather Bureau should be explained, what an observation consists of, how the information reaches Washington, and how the maps are made. A chapter should explain the meaning of the terms "high" and "low," "cyclone" and "anticyclone," the conditions of the weather connected with each, the paths of storms crossing the United States, and should be liberally illustrated with maps and samples of forecasts made at the time. A collection of various methods of utilizing forecasts in agricultural interests should be given—for instance, the methods of protecting vegetation from frost, use of smudge fires, flooding of cranberry fields with water, etc.

Such a bulletin would stimulate interest everywhere, and greatly enlarge the sphere of usefulness of the Weather Bureau and State services.

As I have already exceeded reasonable limits in this communication, I will say but a few words more on the last two subjects before the convention.

I think the inspection of voluntary stations highly important. It is suggested that the regular inspectors of the Weather Bureau should visit voluntary observers at stations along their routes when inspecting stations of the Weather Bureau.

The importance of equipping voluntary observers with shelters lies in the fact that uniformity of exposure is thereby secured, making observation taken everywhere comparable. Differences of opinion as to the size of shelter to be adopted, elevation above the ground, etc., should be laid aside, and nothing could be better than the adoption of the style of shelter recommended by the committee on instrument shelters appointed at the first convention of State weather services in 1892. The report of the committee was signed, I believe, by Messrs. W. L. Moore and J. W. Smith.

With reference to special investigations which can best be undertaken by State weather services, I think none could be more valuable than detailed investigations into the relations of climate to the growth of various crops, for which work State weather services have every facility. Prof. P. H. Mell's report on the climatology of the cotton plant (Bulletin No. 8, of the Weather Bureau) is an indication of what might be accomplished in that line. The great amount of routine work done at most State weather service centers will seriously interfere in most cases with the undertaking of such special investigations. This is the most important subject before the convention, and I hope it will be thoroughly discussed.

REPORT OF COMMITTEE APPOINTED TO INVESTIGATE THE SUBJECT OF STAMPING WEATHER FORECASTS ON MAIL MATTER.

MONTGOMERY, ALA., *November 12, 1895.*

SIR: As chairman of the committee appointed by the Association of American State Weather Services, in convention at Indianapolis, Ind., for the investigation into the merits and practicability of the "postmark logotype" system as suggested by me at the recent convention, I have the honor to submit the following:

Capt. T. F. Townsend, director of the Pennsylvania State weather service, and Mr. S. W. Glenn, director of the South Dakota service, were also appointed members of this committee, but owing to the great distances intervening there has been an inability on the part of the committee to take any concentrated action in this investigation, and it was decided that individual reports be rendered. The report of Captain Townsend will be found among the inclosures; that of Mr. Glenn was evidently lost in the mail, as is evidenced by inclosed letter from him, dated 7th instant. However, he has been requested to forward a copy of his report, which will be transmitted immediately on its receipt.

A circular was sent to the directors of the various State weather services and officials in charge of the Weather Bureau offices in some of the large cities. The circular was issued with the intention of gaining a consensus of opinion as to the merits and demerits of the proposed system with a view to perfecting the same as far as possible before report should be made, and not with a view to forestall any future action by the Weather Bureau. A majority of the replies favor the suggestion, while a few offer objections, which, it is thought, could be overcome with but little difficulty. These objections are nearly all relative to the legibility of the postmark stamp. The only way to either affirm or refute this objection is by giving the system a trial, and it is thought that the postmasters and clerks would be more cautious in stamping when they know that their stamp is to convey other information besides the date of receipt of the letter.

Some of the officials to whom the circular was sent gave the matter to the local press for publication. This was done not through request or desire of mine, and while the kindly spirit which prompted this action is fully appreciated, it would have been preferable to have abstained from publishing it until after the matter was officially acted upon.

It appears from a letter received from the director of the Wisconsin State weather service that the postmaster at Racine, Wis., having his attention called to the newspaper comments on the proposed system, has given it a practical test, and that he has communicated with the Chief of the Weather Bureau and Postmaster-General asking permission to inaugurate this system of distributing weather information. This action of the postmaster at Racine, while demonstrating the feasibility of the system, has hastened the rendering of my report on this matter. It was my intention to wait until all possible information could be gathered before making report, but for the above reason it was thought best to bring it to the attention of the Weather Bureau.

Some of the advantages of such a system of distribution of forecasts are set forth in the circular, a copy of which is inclosed, and it is hardly necessary to dwell upon its many advantages and its many adaptations to distributing weather information and special warnings.

I have not procured a practical working stamp illustrating its mechanical construction, as such was deemed unnecessary at this stage of the matter.

Captain Townsend in his report, inclosed herewith, makes a good suggestion, which is that if this plan of distribution is adopted the forecasts be telegraphed to railway mail clerks, who can stamp them on cards to be deposited in the respective pouches to be distributed to postmasters along balance of their routes, who can distribute their information by the postmark system. Thus one telegram would convey the initial information to a number of distributing postmasters, many of whom might not have telegraphic communication.

I have to report that the suggestion is considered practical, and feel sure that practical tests will develop its merits.

It is thought that should the system be put in extensive use that the cost of stamps might be arranged with the Post-Office Department, so that it and the Weather Bureau would each bear their share of the expense.

After a thorough consideration of the matter I recommend as follows:

First. That this matter be referred to the Chief of the Weather Bureau for his consideration, with the recommendation that the system suggested be adopted and that the necessary cooperation of the Post-Office Department be secured.

Second. That the system be first put in operation in such towns or cities as are already forecast display stations and have a carrier delivery, and that the forecasts be telegraphed to the postmasters of such places, who, if not the displaymen, can furnish the latter a copy of the forecasts.

Third. Should the system prove successful, that the forecasts be telegraphed to railway mail clerks, who will distribute them to postmasters, who will in turn stamp them on mail delivered.

Fourth. That if this system is adopted, it be thoroughly advertised in the press of the country, also through the Official Postal Guide, and that large cardboard bulletin boards describing the system be furnished postmasters for display in their offices.

In conclusion, I beg to say that should the Chief of the Weather Bureau consider the suggestion worthy of adoption, it would afford me pleasure to aid in any manner whatsoever the successful operation of such a system of forecast distribution.

Very respectfully, F. P. CHAFFEE,
Director Alabama State Weather Service,
Chairman of Committee.

Maj. H. H. C. DUNWOODY,
President American Association of
State Weather Services, Washington, D. C.

PHILADELPHIA, PA., *November 6, 1895.*

DEAR SIR: As a member of the committee appointed to investigate and report upon the practicability of distributing forecasts in the rural districts by the "postmark logotype" system, suggested by you at the recent State Weather Service convention, I submit the following:

Owing to the impossibility of giving a practical test of the proposed system, conclusions relative to its merits must necessarily be largely theoretical. These, however, can be based on known existing conditions, which must be used in carrying out the scheme.

The main groundwork for the suggested plan is already provided for by the Government in its prompt and rapid delivery of the mails throughout the rural districts, and with a slight extension of the liberal policy already pursued by the Post-Office Department in its cooperation with the Weather Bureau in disseminating its forecasts, together with suitable logotype stamps for the distributing postmasters and an organized system for furnishing them with the necessary information, the plan will be complete in every detail.

The forecasts to be of value must be the very latest, and without an effective and economical means for placing them in the hands of the postmasters the proposed scheme would be incomplete and objectionable.

This can not be done by wire to each postmaster because of the lack of facilities and the great expense that would attend it. Neither could it in many cases be done by cards from the offices of the Weather Bureau, as the mails frequently leave before the forecasts are issued; but it can be done at a comparatively small expense by wiring the forecasts to railway mail clerks at proper points along their lines, and have them stamp the forecasts by logotype on cards addressed to the various postmasters along the balance of their route, and then place the cards in their respective pouches so that the distributing postmasters will receive the latest information with their mail.

In this manner many post-offices can be reached which have neither telegraphic nor telephonic facilities.

Additional means of communication will naturally suggest themselves when the scheme is once in operation. While, perhaps, one general rule can be given, some districts may require special arrangements which can be worked out by those having the work in charge.

With the forecast for distribution in the hands of the postmaster on the arrival of his mail pouch, I see no reason why he can not, with a suitable appliance, rapidly stamp the forecast on the back of each letter in connection with its date and time of receipt. The wording must, of course, be in a concise form, particularly during its tentative stage.

To summarize, I believe the distribution of forecasts by the "postmark logotype" system perfectly feasible, and one that will be appreciated by the general public. I therefore recommend its favorable consideration.

Very respectfully,

T. F. TOWNSEND,
Observer in Charge.

Mr. F. P. CHAFFEE,
Director Alabama State Weather Service,
and Chairman of Committee.

HURON, S. DAK., *November 7, 1895.*

DEAR SIR: Referring to my communication of 29th ultimo, relative to the duplication of forecasts on mail matter, I beg to state that I believe figures indicating the date would be more distinct and more readily noticed by the public if they were placed around the ordinary postmark. I am still of the opinion that the word "to-morrow" and the forecast should find place in the stamp proper and not in any separate attachment, as indicated in your illustrations.

Since writing you I have noticed closely the manner of using the receipt stamps in the office here, and the liability of any attachment on the outside of the regular style of stamp coming loose and proving a source of annoyance to the stamping clerk is very great.

I would be glad to know the result of your correspondence with the stamp manufacturers, as they are no doubt in position to furnish something substantial.

I realize that my suggestion would necessitate the substitution of new stamps complete by the Post-Office Department, but am unable to see how any attachment to the stamps now in use, except those operated by electricity in the large cities, would work satisfactorily.

Yours, hoping for success,

SAM. W. GLENN.

Mr. F. P. CHAFFEE,
Director Alabama State Weather Service,
Montgomery, Ala.

○

Bulletin No. 19.—W. B., No. 97. Price 15 cents.

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

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REPORT
ON THE
RELATIVE HUMIDITY
OF
SOUTHERN NEW ENGLAND
AND OTHER LOCALITIES.

PREPARED UNDER THE DIRECTION OF
WILLIS L. MOORE,
CHIEF OF WEATHER BUREAU.

BY

ALFRED J. HENRY,
CHIEF OF DIVISION.

WASHINGTON:
WEATHER BUREAU.
1896.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., April 25, 1896.

SIR: One of the conditions essential to the greatest degree of success in the spinning and weaving of cotton fabrics is a humid state of the atmosphere, and the more constant the degree of humidity the greater is the measure of profitable spinning, especially as regards the finer numbers. The average spinning of England is finer than that of the United States, and the average of the latter varies greatly with geographic location, the finer spinning being done almost wholly in New England.*

The attention of the Bureau having been called to the importance of the subject and to the probable extension of the manufacture of cotton over a much wider area than it has yet occupied, a comparison was instituted with a view of ascertaining how the natural humidity of certain portions of the United States, particularly the South, where the extension of the art is most pronounced, compares with that of the southern shore of New England.

Mr. Alfred J. Henry, Chief of the Division of Records and Meteorological Data, was assigned to the duty of making the comparison, and his report is presented herewith.

I have the honor to recommend that it be printed as Weather Bureau Bulletin No. 19.

Very respectfully,

WILLIS L. MOORE,
Chief of Bureau.

HON. CHARLES W. DABNEY, JR.,
Acting Secretary of Agriculture.

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* Report on Manufacturing Industries in the United States, Eleventh Census, 1890, Part III, p. 185.

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REPORT ON THE RELATIVE HUMIDITY OF SOUTHERN NEW ENGLAND AND OTHER LOCALITIES.

The relative humidity of the air is merely a convenient term for expressing comparative dryness or moisture. When the air is completely saturated with aqueous vapor its relative humidity is said to be 100 per cent; when it contains but three-quarters of the amount of vapor necessary for complete saturation, the relative humidity is said to be 75 per cent.

The aqueous vapor in the air is derived primarily from the evaporation of water from the ocean and from the soil, streams, and vegetation of the earth's surface.

The quantity of water that can exist in the form of vapor is determined by the temperature of the air in which evaporation takes place. For example a cubic foot of air at a temperature of 32° F., can contain no more than 2.11 grains of water in the form of vapor; if, however, the temperature of the air be raised to 48°, 64°, and 80°, it can then contain 3.80, 6.56, and 10.93 grains of water vapor at the respective temperatures. It will be observed that the increase in the amount of water vapor is not proportional to the increase of temperature; thus at a temperature of 64° the air can contain more than three times as much vapor as at 32°; at 80° nearly four times as much as at 40°. With a clear understanding of this important fact, it becomes apparent that the relative humidity depends very greatly upon the temperature, as will be referred to again at greater length.

The process of evaporation may be regarded as an attempt on the part of nature to maintain the vapor atmosphere in perfect equilibrium. The latter is being constantly disturbed by other natural phenomena, such as the formation of cloud and fog, the precipitation of moisture in the form of rain, snow, etc. There are several methods of changing water vapor to liquid form, thus diminishing the amount of vapor present in the air. The principal one consists in lowering the temperature of the vapor and the other bodies in contact with it until the point of saturation has been reached. The simplest illustration of this method is found in the formation of dew. During the warm hours of the day the solid particles of the earth's surface proper, together with the bodies of many organic forms, are raised to a temperature much higher than that of the surrounding air. While in this condition, the water vapor present in the air will not condense upon them even if the temperature of the air be cooled to the point of saturation. The same substances, however, which warmed up very fast in the daytime, cool at an equally rapid rate during the night, and soon become cooler than the surrounding air. As soon as they are cooled to the temperature of saturation, vapor molecules begin to condense upon their surfaces.

The relative humidity during the cycle of events just mentioned sinks rapidly with increase of temperature during the heated part of the day, because the higher the temperature the greater the capacity for moisture, and also partly because the surface evaporation is greatly weakened as the day advances. With the approach of night the temperature falls and the relative humidity increases, reaching the highest percentage of the day approximately at the time of lowest temperature.

The relative humidity of a place, whether constant or variable, depends greatly upon the daily and seasonal temperature changes, the amount of cloudiness, the frequency and amount of precipitation, etc. Abundant sunshine and intense radiation are invariably associated with low relative humidity, and marked variation between day and night; on the other hand, excessive cloudiness and a small range of temperature conduce to a high degree of relative humidity, with slight changes from day to night.

The distribution of aqueous vapor through the atmosphere is chiefly controlled by the movements of the air in its local and general circulation. If the atmosphere were perfectly quiet and everywhere of a uniform temperature, no condensation would take place, while the aqueous vapor would be equally diffused in all directions, satisfying the law of diffusion of gases. But since such is not the case in nature, it follows that the amount of aqueous vapor in the air at any place must vary with changes both in local atmospheric conditions and the season of the year. And while these variations may be of considerable moment on individual dates or in a particular season, yet in the long run the average of accumulated observations for any region may be safely used to show the distinctive characteristics of that region.

The results of a comparison of the relative humidity of the southern shore of New England with that of certain other localities in the United States and abroad are given on the following pages.

The stations selected.—Choice of stations in New England, as also in other regions, was necessarily restricted to those points at which observations were made at the same hours and on a uniform plan. New Bedford and Woods Hole, Mass., Newport, R. I., and New London, Conn., were selected to represent the coast region of southern New England; Mobile, Ala., was chosen as a point on the Gulf Coast most nearly resembling in environment the New England stations; Atlanta, Ga., and Charlotte, N. C., were selected as representative of inland stations of moderate elevation on the Piedmont Plateau; and

Augusta, Ga., and Wilmington, N. C., as representative of the tide-water stations of this region. Oswego and Utica, N. Y., were also selected on account of certain distinctive climatic features, as will appear subsequently.

The elevation above sea level of Atlanta is 1,050 feet; Charlotte, 725 feet; Utica, 537 feet; Oswego, 304 feet, and Augusta, 128 feet, The remaining stations—New Bedford, Woods Hole, Newport, New London, Wilmington, and Mobile are practically at sea level.

The thermometers were exposed at the following heights above ground:

New Bedford		6 feet.
Woods Hole		7 "
Newport		19 "
New London		29 "
Oswego		34 "
Utica		2 "
Charlotte		34 "
Wilmington	January, 1878, to November, 1879	26 "
	November, 1879, to December, 1880	62 "
Atlanta		78 "
Augusta	January, 1878, to December, 1878	28 "
	January, 1879, to December, 1880	19 "
Mobile		32 "

The observations.—The observations used, with the exception of those at New Bedford and Utica, were made by Signal Service (now Weather Bureau) observers, at 7 a.m., 2 p.m., and 9 p.m., local mean time, during the years 1878, 1879, and 1880. The single-louvre window thermometer shelter was in use during that period, and artificial ventilation was not resorted to, as at present. The relative humidity was deduced from readings of the wet and the dry bulb thermometers by the formula given in Guyot's Meteorological and Physical Tables, published by the Smithsonian Institution.

The observations at New Bedford were made by Mr. Thomas R. Rodman, voluntary observer for that place, and one of the most careful and experienced of the voluntary observers cooperating with the Weather Bureau. Mr. Rodman recorded the readings of both wet and dry thermometers, but did not compute the relative humidity, the necessary computations being made in the Central Office of the Weather Bureau.

The Utica observations were made by Mr. Thomas Birt, Voluntary Observer, Weather Bureau, during parts of the years 1888, 1889, 1890, and 1891. The series is much broken and is also incomplete, there being no 2 p. m. observation. Mr. Birt's thermometer shelter was fastened to a tree 27 feet in the rear of his house and 2 feet above ground.

Accuracy of observations.—It should be remembered that the relative humidity of the air can not be determined with the same precision as its temperature or pressure. It is doubtful, indeed, whether the most accurate observers, working under identical instructions, can arrive at results agreeing within 1 per cent at temperatures above freezing, and even greater differences will occur at temperatures below freezing.

General remarks.—The term "relative humidity," as stated at the outset, is merely a comparative expression of a physical fact, viz, the proximity to saturation of the air at a given moment, and conveys no idea of the absolute amount of moisture in the air. The latter is relatively constant, and follows more or less closely the seasonal temperature, the amount contained in the air at any point being dependent upon the temperature of the place and its situation with reference to large bodies of water.

Over the ocean the mean daily relative humidity is, on the average of the year, between 80 and 90 per cent; over the land it varies from the dryness of the desert, 50 per cent and less, to 90 and 95 per cent at points where the conditions are most favorable to complete saturation. Generally it is greatest in winter and least in summer.

New England group.—The topographic features of the stations comprising this group are not sufficiently divergent to effect the humidity conditions to a marked extent. The station at Woods Hole is situated on a narrow strip of land not more then five hundred feet from the waters of Little Harbor on the one side and Great Harbor on the other. The adjacent land is low and flat, there being no portion of it within a mile of where the observations were made above one hundred feet in elevation. These conditions are all favorable to a high and fairly constant degree of relative humidity; in fact, at no other station are the conditions so favorable for a maximum degree of saturation as at Woods Hole.

It would appear from an examination of the figures in Table I that the percentage of relative humidity at New Bedford is considerably higher than at any other station. Further examination, however, shows that it is only in the colder months of the year and at the morning and night observations (see Table II) that the differences between New Bedford and the remaining stations are pronounced. A careful consideration of the New Bedford observations leads to the conclusion that the conditions shown to exist at the morning and night observation hours in cold weather are more or less artificial, due to errors in observation or some local effect not heretofore understood or explained.

The general characteristics of the New England group may be summed up as follows:

The air is about three-quarters saturated with water vapor on the average of the year. The lowest monthly average is about 70 per cent; the highest, 80 per cent. The greatest change from one month to another is about 6 per cent from September to October. At individual stations the greatest variations are: New Bedford, 7 per cent, March to April; Woods Hole, 6 per cent, September to October; New London, 6 per cent, September to October; and Newport, 5 per cent, September to October.

August and September are the most humid months; April and May the driest. The distribution of relative humidity throughout the year is graphically shown on Plate I.

New England compared with Mobile.—Mobile, on account of its environment, was selected as a probable point in the Southern States where the relative humidity should agree quite closely with that of the southern shore of New England. That it *does* so agree, so far as the general distribution is concerned, can easily be seen from the curves on Plate I, and the numerical values in Table I. The only notable difference is in the time of occurrence of the maximum degree of saturation, viz: in winter instead of in July and August as in New England. There is, however, a secondary maximum in the months of chief maximum in New England, August and September. While the general features of the relative humidity at both Mobile and southern New England are in close accord, considering only the monthly averages, there is a well-marked difference in the diurnal variation as will be shown later.

New England and Mobile as compared with Piedmont Plateau.—The curves representing the annual march of relative humidity on the Piedmont Plateau and south Atlantic Coast are essentially different from those of southern New England and Mobile. There is a remarkable decrease in the relative humidity in February as compared with December and January, and the fall continues until June, when the lowest limit is reached. The relative humidity then increases to a maximum in August, decreasing again to a second minimum in November. Although the inland stations of this group are rather widely separated, the monthly averages are in close accord and indicate clearly (*a*) that the variations from month to month are greater than on the southern New England or Gulf coasts; (*b*) that the greatest extremes of dryness are reached in the late winter and spring months, February to May, inclusive, and (*c*) that the air is considerably drier on the average than on the Gulf Coast or southern New England.

The differences here noted are chiefly those due to geographic location with respect to large bodies of land or water. The coast stations partake more or less of the climate of the ocean, particularly if situated so that the prevailing winds are from the sea. In the summer season the winds of southern New England are chiefly from the south and southwest, thus tempering the climate of the land and insuring a uniform supply of moisture. The climate of New England, the year round, is noted for its changeableness, its great ranges of temperature, and the alternating of clear and cloudy skies at short intervals. The great atmospheric disturbances which are continually moving across the country, pass directly over or near its borders. Each cyclonic storm causes an increase of temperature and more or less cloudy weather, and a varying period of complete saturation.

The climate of the Piedmont Plateau and south Atlantic and Gulf coasts differs from that of New England in that the weather conditions are more settled; the number of cyclonic storms, as compared with those of New England, is in the ratio of about one to three. The cloudiness is less, as is also the number of rainy days, although the rainfall is from 10 to 15 per cent greater. The winds of summer, except on the immediate coast, are warm and relatively dry, as compared with the southerly winds so prevalent on the southern coast of New England.

The low relative humidity of the spring and early summer months at the inland stations of the South is in strong contrast to the conditions that obtain on the coast. Wilmington though 8 or 10 miles distant from the sea, shows the influence of the water very plainly.

Northern Central New York.—The causes which contribute to a more or less uniform condition of relative humidity on the sea coast are also effective in producing a fairly constant degree of humidity near the Great Lakes, notably in northern-central New York, over a region extending eastward through a portion of the Mohawk Valley.

The distinguishing characteristics of this part of the State are: (1) a large number of rainy days, although the amount on each day is small; (2) excessive cloudiness, and (3) a temperature modified by proximity to the lakes. The cloudiness is considerably greater than that of New England, and much greater than that of the South. The cloud layer serves as a screen to protect the earth from excessive insolation by day and radiation by night. The temperature is, therefere, more uniform than it would otherwise be, and the changes in relative humidity correspondingly less. Unfortunately, the observations of relative humidity for this region are quite meagre, unless we accept those made at Oswego or Rochester. The series at Utica is incomplete, there being no midday observation. At the morning and evening hours, however, the relative humidity appears to be quite constant, and the air is more nearly saturated than at Oswego directly on the lake. The Mohawk Valley, in which Utica is situated, is a deep depression between the highlands of northern and central New York. The prevailing winds are almost exclusively in the direction of the valley, viz: easterly and westerly. The valley winds at night are almost invariably cool and, consequently, relatively moist. The 2 p. m. observation at Oswego shows that in the warmer months of the year the midday humidity is not greatly different from that of southern New England. By reference to Table VII it will be seen that the monthly mean temperatures of Utica and Oswego are practically the same. It is therefore reasonable to assume that their humidities are not widely different.

Extreme monthly variation.—The extreme variation, at all stations thus far considered, during the year is as follows:

(Greatest monthly average minus (—) least).

Woods Hole	12 per cent
New Bedford	10 per cent
Newport	7 per cent
New London	6 per cent
Oswego	8 per cent
Charlotte	17 per cent
Wilmington	6 per cent
Atlanta	17 per cent
Augusta	10 per cent
Mobile	8 per cent

The foregoing statements include the main points of difference, considering only the monthly means.

Diurnal Variation.—Each monthly mean should be considered as a composite made up of the means at 7 a. m., 2 and 9 p. m. The diurnal variation of relative humidity in its simplest phase, is as follows: The maximum takes place during the early morning hours, and the minimum from 1 to 4 p. m., being simply the inverse of the daily temperature changes. The mean relative humidity at 7 a. m., in the winter months, is considerably above the mean of the twenty-four hours, but with the approach of summer the difference becomes less. The mean at 2 p. m. represents fairly well the lowest point reached during the day, while the mean at 9 p. m. is greater than the daily mean.

Differences as shown by means at 7 a. m., 2 and 9 p. m.—The means at 7 a. m., 2 and 9 p. m. have been calculated for each of the stations examined, and the results will be found in Table II and in diagrammatic form for January and July on Plate II.

It is at once apparent that while the monthly means at any two places may agree within a fraction of one per cent, there may be considerable difference in the daily range; thus the monthly means of Newport and Mobile for March are identical—72.3 per cent—yet the range at Mobile is from 85 per cent at 7 a. m. to 55 per cent at 2 p. m., while at Newport the range is from 77 per cent at 7 a. m. to 65 per cent at 2 p. m. While this is an extreme case it illustrates very forcibly the main point of difference between the humidity regime of the two places. Table III (from which the foregoing illustration was drawn) was prepared to show the extent of the variation from 7 a. m. to 2 p. m., or from 2 to 9 p. m. for all stations. (See also Plate III.)

From these data it will be observed that the relative humidity at Woods Hole is more constant than at any other station. It is likewise the station most exposed to the influence of the ocean. The greatest variations are found at Augusta, Wilmington and Mobile, in the order named. The variations at New Bedford are believed to be unduly large, and they have not been considered as representing southern New England.

Influence of the winds.—The distribution of relative humidity throughout the day at the New England stations differs again from that of the southern stations on account of the prevailing winds. On the southern coast of New England the prevailing winds of the warmer months (especially at 2 and 9 p. m.) are from the south and southwest, directly from a water surface cooler than the land. As a result the relative humidity during the warmer hours of the day is kept at a figure not far from the average at 7 a. m., while at 9 p. m. the amount is even greater than in the morning, thus reversing the conditions which obtain at interior stations.

The prevailing winds of New England in winter are from the northwest. The northwest wind is a dry wind throughout the year and tends to maintain the relative humidity, during its prevalence, at or near the lowest limit of the year.

The wind system of Mobile is somewhat different from that of New England, as will be seen by the table which follows. The percentage of northerly winds at Mobile is much greater than at Newport. In winter the north wind at Mobile is relatively drier than the same wind in New England, particularly during the warmest part of the day. In summer the reverse is the case during the morning and evening, but the north winds of the warmest portion of the day are relatively drier than those of New England. The winds from water surfaces at Mobile do not differ greatly from similar winds on the southern shore of New England.

The winds at inland stations are less regular; that is to say, they do not blow from any one quarter with the regularity observed on the sea coast. They are of course drier than the coast winds.

The relative humidity of the winds varies greatly with the hour of the day, the season of the year, and the geographic location of the place. The following table shows the relative humidity of the various winds for January and July at four stations only.

Relative humidity of the various winds for January and July.

(The number of winds is given in the column headed "W.")

JANUARY.

Direction.	Newport.						Charlotte.					
	7 a. m.		2 p. m.		9 p. m.		7 a. m.		2 p. m.		9 p. m.	
	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.
N	14	81	7	73	8	77	10	82	8	67	10	74
NE	7	71	6	79	5	77	28	80	16	70	18	72
E	4	92	4	85	4	90	9	85	14	62	14	73
SE	2	95	8	71	4	88	8	95	5	58	5	74
S	2	96	4	58	9	88	8	88	10	62	10	82
SW	20	83	23	74	17	76	16	82	21	58	18	72
W	22	70	21	54	25	65	9	88	11	58	6	79
NW	19	70	23	56	18	66	8	79	8	53	11	56
C	8	71	1	65	3	74	2	100	......	......	1	87

Direction.	Wilmington.						Mobile.					
	7 a.m.		2 p.m.		9 p.m.		7 a.m.		2 p.m.		9 p.m.	
	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.
N	14	78	10	60	7	69	28	82	27	54	21	66
NE	24	81	12	55	12	80	4	71	4	41	5	76
E	4	87	8	56	12	79	5	84	4	57	3	76
SE	12	79	10	62	5	81	5	95	7	77	4	88
S	3	61	6	57	6	83	28	97	37	75	36	92
SW	14	82	15	51	19	77	4	94	8	58	6	84
W	11	95	12	60	7	67	1	69	5	52	2	78
NW	10	76	16	45	11	61	9	82	6	55	6	73
C	10	86	3	62	12	81	14	93	......	......	9	85

JULY.

Direction.	Newport.						Charlotte.					
	7 a.m.		2 p.m.		9 p.m.		7 a.m.		2 p.m.		9 p.m.	
	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.
N	12	77	2	66	4	71	7	65	5	61	6	70
NE	8	73	4	54	4	71	11	77	4	49	8	74
E	2	92	6	68	2	76	5	79	10	50	1	75
SE	2	92	6	65	6	83	4	81	5	58	7	68
S	12	87	19	65	18	82	8	85	8	53	17	70
SW	34	84	44	69	44	86	11	79	12	51	6	66
W	3	72	3	62	4	68	10	71	12	49	4	81
NW	17	71	6	47	4	72	5	64	6	43	5	57
C	3	84	......	......	7	80	1	95	......	......	2	56

Direction.	Wilmington.						Mobile.					
	7 a.m.		2 p.m.		9 p.m.		7 a.m.		2 p.m.		9 p.m.	
	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.	W.	R.H.
N	2	86	1	44	2	88	28	84	7	61	12	88
NE	22	80	6	64	6	78	5	86	6	58	3	88
E	10	82	16	59	15	70	7	83	8	68	3	77
SE	3	75	17	55	11	79	6	81	11	60	7	84
S	5	88	24	62	24	74	18	80	38	59	25	78
SW	25	85	15	64	25	88	11	84	10	70	20	78
W	15	79	8	50	1	86	14	82	8	74	9	76
NW	3	83	5	54	2	80	9	81	3	73	7	89
C	8	86	1	75	6	79	5	88	1	64	7	88

The foregoing table presents a variety of detail that the reader may study for himself. The broader generalizations suggested by the data, are as follows: (*a*) The northwest wind is the dry wind at almost all stations and for all seasons, an exception being noted in the case of Mobile for 9 p. m. of July. Here the winds from a northerly quarter are the relatively moist winds. A warm wind blowing over a cooler surface, or a wind that by any means loses a portion of its heat without the condensation of any of its moisture, becomes a relatively moist wind. (*b*) The winds from the sea are generally the more constant as regards vapor contents, a notable example being the southwest wind of the New England Coast. (*c*) A moist wind on the immediate coast does not necessarily carry its moisture a considerable distance inland; the contrary is sometimes the case; for example, the northeast wind at Wilmington in January, although almost direct from the sea, is relatively drier than the same wind at Charlotte, nearly 200 miles inland. This is probably an effect of the higher temperature at Wilmington during the winter months.

Accidental variations.—Thus far monthly means only have been considered. It is now proposed to look into the fluctuations due to sudden changes in temperature and other atmospheric conditions. In order to compare the sudden and marked changes in relative humidity, the observations were examined to find the greatest change, whether a rise or fall, from one observation to the next succeeding one, and the changes so found were tabulated and averaged. The averages are given in Table IV. The sudden changes are generally greater at the southern stations, except in July and August, when the changes in New England are greater than those at Charlotte and Atlanta, and about equal to those of the remaining southern stations.

Lowest relative humidity; individual cases.—Table V shows the averages of the lowest individual cases of relative humidity recorded each month of the years of observation. As in the case of the greatest range, the lowest values occur in the spring months and at the inland stations of the South. These data are important as showing the lowest limit of dryness reached in the respective sections. The degree of dryness that prevails at times for periods of twenty-four and forty-eight hours, is shown by the data of Table VI. Generally these periods of extreme dryness do not extend over two or three days.

Relative humidity inside and outside.—The ordinary thermometer shelter is generally placed on the roof of a building, or attached to a window facing the north, or failing these, is placed on a ground support at some distance from the building.

In applying statistics of relative humidity obtained from instrumental readings made in the open air in the ordinary thermometer shelter to inside conditions, it may be well to inquire, "What is the relation between the humidity inside of a building and outside of it?"

ginning March 1, 1896, the relative humidity of the observers' room, third and top story of the Weather Bureau building, was determined at the time of making the 2 p. m. observation. The room is heated by steam and fairly well ventilated. An open stairway leads to the halls below.

The average temperature of the room during March was 72°, relative humidity 32 per cent; the average outside air temperature was 32°, relative humidity 64 per cent. The outside humidity ranged from 38 per cent to complete saturation, 100 per cent; the inside from 24 to 57 per cent. The extreme variation from one day to another at the same hour was, outside 46 per cent, inside 24 per cent. The variations inside were on the average very much less than on the outside, as would be expected by reason of the uniform temperature inside. The March observations are fairly typical of a winter month when the conditions are most favorable for extreme dryness. When, however, the outside and inside temperatures approach each other, the relative humidities also become more nearly equal.

Thirteen observations have thus far been made in the present month (to April 22), with the following results: Outside temperature 68°, relative humidity 46 per cent; inside temperature 78°, relative humidity 37 per cent; ranges in relative humidity, outside, from 32 to 81 per cent; inside, from 25 to 44 per cent; greatest daily range, outside, 43 per cent; inside, 13 per cent.

From the 13th to the 21st mid-summer weather prevailed, the average temperatures inside and outside being 83.4° and 84.6°, respectively. The relative humidities during the same period were 40 and 41 per cent, respectively. The foregoing facts show, among other things, the importance of a uniform temperature whenever uniform humidity conditions are desired, and that outside hygrometric observations cannot be relied upon as giving true humidity values for the interior of buildings except when the temperatures, inside and outside, are practically the same.

Manufacture of cotton abroad; climatic influences affecting.—The manufacture of cotton is carried on in various parts of the globe and under widely different climatic influences. The oldest cotton producing country is India, where it has been grown and manufactured from time immemorial. Cotton fabrics were known in China before the Christian era, and early mention is made of the cultivation of the plant in Egypt, Asia Minor and in other countries bordering on the Mediterranean. The manufacture of cotton on an extensive scale, however, appears to have centered in and about Manchester, England, from an early period of the seventeenth century. The idea that the tendency to concentrate the cotton manufacturing industry in Lancaster was originally due to the advantage of climatic conditions, can hardly be entertained. To cheaper accommodations for carrying on the work, the lower wages of workmen, the proximity to rich coal fields, and the advantages of water transportation must be ascribed the great development of the industrial arts that has made Manchester famous throughout the civilized world. Some of the causes that once operated to concentrate the industry in Manchester are now operating to distribute it to the outlying towns and villages. The town of Oldham, about 6 miles northeast of Manchester, at an elevation of 688 feet above mean sea level, is one of the most important seats of cotton manufacture in the world. Its importance is largely due to the fact that it is on the edge of the Lancashire coal field where the mineral is very easily obtained.

Lancashire, climate of.—It has not been possible to obtain statistics of relative humidity for either Manchester or Oldham, but sufficient data have been obtained from the reports of the Royal Meteorological Society for surrounding points in Lancashire, Derby, Cheshire, and Stafford (as shown on Plate IV) to arrive at a very close estimate of the conditions which prevail throughout Lancashire. The climate of Lancashire has no counterpart in the United States. The range of temperature is exceedingly small (see Table VII), the summers are cool, and there is little change from day to night. The rainfall is a little less than that of New England, but the number of rainy days is greater. The cloudiness is greater than in any portion of the United States, as is also the relative humidity. The latter is remarkably constant, on account of the even temperature and the extremely small daily range. It should be remembered, however, that the averages of relative humidity for English stations have been computed from but two, and in some cases but one, daily observation. They are not therefore strictly comparable with those of American stations, in which a midday observation has been included. As before stated, the capacity of the air for vapor increases very greatly with the temperature. At a temperature of 40° saturated air contains 2.86 grains of aqueous vapor per cubic foot; at *twice* that temperature (80°) a cubic foot contains nearly four times as much vapor, viz: 10.93 grains. The mean summer temperature of Oldham is not far from 58°; *at that temperature the capacity of the air for vapor is about one-third less than it is in southern New England, with a mean summer temperature of* 68°. The amount of vapor sufficient to cause a high relative humidity at Oldham would, therefore, cause only a moderate degree of saturation at the temperatures which obtain in New England. The conditions which dominate the weather of Lancashire come chiefly from the Atlantic Ocean. In the United States the controlling influences come from the west, giving more or less of a continental character to the weather of the eastern seaboard.

India, climate of.—The extensive erection of cotton mills in Bombay, the Madras Presidency, and Bengal, within recent years, has caused the Lancashire merchants to fear the competition of India. The climatic conditions of Bombay, Madras, and Dacca are shown in Tables I, VII, VIII, and IX.

The predominating features of Indian climate are the semiannual reversal of the wind system and associated phenomena. The figures given in the tables above named have been taken from Report on the Meteorology of India, 1890, John Eliot, M. A., Calcutta, 1892, to which the reader must be referred for further details as to the climatic phenomena of that country.

Attention is directed to the averages of relative humidity at Dacca, which place, it will be remembered, is famous for the exquisite texture of its muslins. The annual march is not unlike that of the Piedmont Plateau, except as regards the strength of the maximum during the southwest monsoon. The manufacture of cotton in India by native artisans is not confined to any particular locality, but is diffused throughout the central provinces and on both coasts under widely varying climatic conditions.

From the foregoing it would appear that thus far in the development of the cotton manufacturing industry little account has been taken of climatic conditions as affecting the quantity or quality of the output. It is also apparent that the relative humidity of the atmosphere depends not only on the absolute quantity of vapor present in the air, but also on the temperature which determines the point of saturation, and that these elements vary both as regards time and geographic situation.

The control of both temperature and humidity by artificial means seems to be the final solution of the problem in all cases where the establishment of mills in a relatively dry section is contemplated.

TABLE I.—*Monthly mean relative humidity at the stations named for the three years* 1878, 1879, *and* 1880, *except at Utica and the foreign stations.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass	83.7	86.0	82.8	76.1	75.6	78.5	82.1	83.2	85.7	81.8	81.5	87.0	82.0
Woods Hole, Mass	76.0	77.1	74.4	73.9	74.3	78.9	82.5	82.9	79.7	73.7	70.7	74.8	76.5
	*87.0	85.0	83.0	81.0	89.0	87.0	87.0	86.0	89.0	80.0	82.0	83.0	84.0
Newport, R. I	71.5	72.8	72.5	71.6	71.5	75.2	75.7	78.7	78.8	73.4	72.9	74.2	74.0
New London, Conn	74.5	71.9	71.5	69.1	70.5	74.6	77.1	78.4	79.1	72.8	70.1	71.8	73.4
	†76.0	75.0	73.0	72.0	80.0	81.0	79.0	82.0	82.0	77.0	77.0	76.0	77.0
Oswego, N. Y	73.9	71.7	69.8	68.4	67.2	72.3	69.8	72.0	71.5	69.6	71.6	74.8	71.0
Utica, N. Y	.....	.....	.....	80.2	83.2	82.6	85.4	84.7	89.2	80.2	81.4	.....	.....
Charlotte, N. C	72.4	62.6	60.5	58.5	60.6	58.2	65.7	75.0	67.0	67.6	67.8	71.7	65.6
Wilmington, N. C	70.2	66.8	66.2	64.9	70.6	70.5	78.6	78.6	75.0	74.3	72.2	71.4	71.2
Atlanta, Ga	69.4	58.0	56.5	58.5	60.6	59.1	68.3	73.3	69.2	69.8	65.8	69.3	64.4
Augusta, Ga	73.8	63.9	62.1	63.2	61.0	60.0	64.6	71.1	69.7	71.9	73.0	72.1	67.2
Mobile, Ala	77.6	72.0	72.3	71.6	73.2	71.9	75.1	76.7	75.2	77.2	78.6	79.5	75.1
English stations.													
Lancaster, Lan	.....	90	80	71	74	78	78	84	82	84	87	90	82
Blackpool, Lan	90	88	80	72	74	79	76	81	82	85	89	90	82
Bolton, Lan	90	89	80	73	72	73	76	82	80	86	89	89	82
Macclesfield, Ches	90	90	84	77	78	77	80	84	86	88	90	90	85
Northwich, Ches	.....	94	86	83	82	78	80	75	80	87	93	92	84

* From observations at 8 a. m. and 8 p. m., 2¼ years.
† From observations at 8 a. m. and 8 p. m., 7 years.

TABLE I.—*Monthly mean relative humidity at the stations named, etc.*—Continued.

States.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
English stations—Cont'd.													
Buxton, Derby. ‡	88	90	88	86	82	82	84	86	88	89	90	91	87
Cheadle, Staf. ‡	90	92	87	88	78	80	85	86	88	89	92	92	87
Indian stations.													
Bombay	70	69	73	75	74	82	87	87	86	80	71	70	77
Dacca	69	64	67	78	80	87	87	87	86	80	72	71	77
Madras	74	73	74	74	69	64	67	71	73	79	80	78	73

‡ Mean of 9 a. m. and 9 p. m. observations; mean of 9 a. m. obs. at other English stations.

TABLE II.—*Monthly mean relative humidity at the hours of* 7 *a. m.*, 2 *and* 9 *p.m.*, *local mean time, at the stations named below* (1878–1880).

Station.	January.			February.			March.			April.			May.			June.		
	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.
New Bedford, Mass	94	69	90	94	76	89	88	72	89	81	62	85	79	62	86	80	68	87
Woods Hole, Mass	79	72	76	79	74	78	78	68	77	77	67	78	75	67	81	79	72	86
Newport, R. I	76	65	78	78	66	75	77	65	74	78	62	75	77	61	77	80	66	80
New London, Conn	79	67	77	77	68	75	76	68	75	74	59	75	78	62	76	78	66	80
Oswego, N. Y	78	69	75	76	67	72	75	68	71	72	68	70	74	59	68	79	65	73
Utica, N. Y.*	....	....	....	....	....	....	....	....	....	80	....	80	84	....	82	85	....	80
Charlotte, N. C	83	62	72	76	50	61	73	47	62	71	44	61	72	46	64	67	45	68
Wilmington, N. C	82	56	74	78	50	71	79	48	72	76	46	78	80	55	77	79	55	77
Atlanta, Ga	78	61	69	68	49	58	68	46	56	69	48	58	72	48	62	69	47	61
Augusta, Ga	83	61	77	78	49	65	78	44	65	76	46	67	74	43	67	73	43	64
Mobile, Ala	88	64	80	88	57	76	85	55	77	81	56	77	88	57	79	80	59	77

Stations.	July.			August.			September.			October.			November.			December.		
	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.	7.	2.	9.
New Bedford, Mass	86	70	90	87	71	91	91	75	91	89	69	86	92	68	85	92	78	91
Woods Hole, Mass	83	78	87	86	75	88	84	72	88	80	67	75	75	65	72	78	71	75
Newport, R. I	80	65	82	83	69	84	85	68	82	81	64	76	79	66	73	78	68	77
New London, Conn	79	69	84	82	69	84	84	70	84	80	61	77	76	62	72	75	66	74
Oswego, N. Y	76	60	73	81	62	78	81	61	73	77	60	71	76	66	72	78	72	75
Utica, N. Y	86	...	85	85	....	84	91	....	88	81	....	80	84	....	79	....	....	....
Charlotte, N. C	76	51	70	84	62	78	80	51	70	80	51	71	79	54	69	82	60	73
Wilmington, N. C	82	59	79	86	66	84	86	59	80	86	56	81	83	56	78	82	58	75
Atlanta, Ga	73	52	65	84	60	76	81	57	70	79	58	71	76	57	65	79	61	69
Augusta, Ga	76	48	70	82	55	76	81	54	75	83	56	76	83	58	77	82	58	76
Mobile, Ala	82	63	81	89	56	85	86	58	82	87	62	82	88	64	84	86	70	82

TABLE III.—*Daily range of relative humidity as deduced from observations at* 7 *a. m.*, 2 *and* 9 *p. m.*, *local mean time, at places named.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass	25	18	17	23	24	19	20	20	16	20	24	14	20
Woods Hole, Mass	7	5	10	11	14	14	9	13	12	13	10	7	10
Newport, R. I	11	12	12	16	16	14	17	15	17	17	13	10	14
New London, Conn	12	14	13	16	14	15	15	15	14	19	14	9	14
Oswego, N. Y	9	8	12	10	15	14	16	18	20	17	10	6	13
Utica, N. Y †	....	....	....	....	....	....	....	....	....	....	....	....	....
Charlotte, N. C	21	26	26	27	26	22	25	22	29	29	25	22	25
Wilmington, N. C	26	28	31	30	25	24	23	20	27	30	27	24	26
Atlanta, Ga	17	19	22	21	24	22	21	24	24	21	19	18	21
Augusta, Ga	22	29	34	30	31	30	28	27	27	27	25	24	28
Mobile, Ala	24	26	30	25	26	21	19	33	28	25	24	16	25

* Observations at 7 a. m. and 9 p. m. only. † Can not be had; no observations at 2 p. m.

Three years observations, 1878–1880. It should be understood that the values given do not express the true daily range, but simply the closest approximation thereto that can be obtained from observations at the hours above named. Generally the 7 a. m. mean has been considered as the maximum and the 2 p. m. mean as the minimum; in the summer, however, the maximum at New England stations occurs at 9 p. m.

TABLE IV.—*Greatest change in the relative humidity of the air in eight consecutive hours during the years* 1878, 1879, *and* 1880.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass	55	53	63	68	48	50	48	47	40	47	60	50	52
Woods Hole, Mass	50	39	44	42	47	40	36	45	34	43	41	41	42
Newport, R. I	55	44	48	47	45	43	47	43	40	49	48	34	45
New London, Conn	45	44	48	50	51	41	40	41	37	50	42	45	44
Oswego, N. Y	35	37	39	44	47	39	39	49	43	55	35	36	42
Utica, N. Y*	....	....	....	....	....	....	...	....	....	....	....	....	..
Charlotte, N. C	63	63	64	55	53	42	39	39	46	52	58	52	52
Wilmington, N. C	59	62	69	61	58	54	45	40	52	59	61	58	56
Atlanta, Ga	49	54	52	49	42	48	38	40	45	45	47	48	46
Augusta, Ga	57	60	65	64	62	52	50	46	53	57	52	60	56
Mobile, Ala	59	63	63	61	49	42	43	46	49	56	51	54	53

*Can not be obtained; no observation at 2 p. m.

The greatest change, whether a rise or fall in each month of the period named, was tabulated and the average change for the entire period was then obtained; thus, at Augusta, the greatest change in January of 1878 was 52 per cent; 1879, 59 per cent; 1880, 60 per cent; the average change for the month being 57 per cent.

TABLE V.—*Lowest relative humidity at the stations named during the years* 1878, 1879, *and* 1880.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass	42	44	32	31	39	36	45	46	49	39	35	38	40
Woods Hole, Mass	36	40	34	37	31	39	46	48	43	33	38	45	39
Newport, R. I	26	38	31	31	28	29	33	44	40	31	34	47	34
New London, Conn	35	31	24	26	27	34	43	44	38	25	32	40	33
Oswego, N. Y	47	45	40	37	30	41	39	39	43	31	45	49	40
Utica, N. Y.*	....	....	....	54	63	63	57	68	76	58	59†	....	....
Charlotte, N. C	25	21	12	15	22	26	33	43	28	23	21	27	25
Wilmington, N. C	24	19	17	17	24	31	37	43	35	22	24	26	27
Atlanta, Ga	27	22	17	21	25	25	32	38	33	25	26	28	27
Augusta, Ga	26	20	20	17	22	23	26	36	33	27	30	28	26
Mobile, Ala	24	23	16	19	28	34	40	45	36	28	26	23	28

*Observations at 7 a. m. and 9 p. m. only. †For ten days.

The lowest relative humidity during each month of the period named was tabulated and the average of each month was then calculated. The figures, therefore, represent the average of the lowest degree of humidity each month.

TABLE VI.—*Lowest daily mean relative humidity for periods of twenty-four and forty-eight consecutive hours, respectively, during the three years* 1878–1880.

MEANS OF TWENTY-FOUR HOURS.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass	65	62	54	52	52	54	64	69	63	58	64	66	60
Woods Hole, Mass	58	56	51	51	50	52	60	63	54	45	50	58	54
Newport, R. I	47	55	50	50	44	49	54	59	54	49	51	57	52
New London, Conn	49	50	44	43	39	49	58	62	58	43	50	54	50
Oswego, N. Y	59	53	57	52	46	58	57	58	56	54	53	60	55
Utica, N. Y.*	....	....	....	60	70	68	66	75	82	63	66	....	....
Charlotte N. C	42	38	33	33	37	41	44	55	45	45	40	47	42
Wilmington, N. C	41	39	34	36	46	50	53	59	52	44	44	44	45
Atlanta, Ga	42	34	29	32	39	38	43	54	51	42	39	40	40
Augusta, Ga	49	41	40	38	39	45	45	57	50	45	44	50	45
Mobile, Ala	45	48	34	41	50	53	61	69	59	55	53	47	51

MEANS OF FORTY-EIGHT HOURS.

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
New Bedford, Mass	74	67	63	55	56	59	66	71	70	63	67	73	65
Woods Hole, Mass	62	60	60	54	53	55	65	67	56	50	52	59	58
Newport, R. I	55	60	51	53	49	50	59	63	58	54	52	63	56
New London, Conn	56	54	49	45	47	52	62	63	62	49	54	59	54
Oswego, N. Y	63	62	59	55	54	59	59	61	58	56	57	63	59
Utica, N. Y	....	....	....	68	55	70	74	76	84	69	69	....	....
Charlotte, N. C	50	42	37	36	42	43	44	56	48	50	45	49	45
Wilmington, N. C	49	46	45	38	50	52	59	63	59	49	50	47	51
Atlanta, Ga	46	37	32	34	40	41	45	56	52	44	41	46	43
Augusta, Ga	53	46	43	42	46	47	46	59	54	50	51	58	49
Mobile, Ala	50	51	42	43	55	54	62	70	61	58	56	53	55

* Observations at 7 a. m. and 9 p. m. only.

In obtaining the figures given in the above table the lowest daily mean relative humidity for each month of the period was tabulated and the mean of the three years calculated.

TABLE VII.—*Monthly mean temperature at the stations named* (*degrees F.*).

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Length of record.
New Bedford, Mass	28	29	35	44	55	64	70	68	62	52	42	32	48	78
Woods Hole, Mass	31	32	36	44	55	63	68	68	63	53	44	36	50	9
Newport, R. I	30	32	36	44	54	64	70	70	64	55	42	34	50	8
New London, Conn	29	30	35	46	56	65	71	69	64	53	43	34	50	18
Oswego, N. Y	24	25	30	42	54	64	70	68	62	50	39	29	46	19
Utica, N. Y	21	22	29	43	56	65	69	67	60	48	35	26	45	5
Charlotte, N. C	42	46	50	60	69	76	79	76	71	61	51	44	60	13
Wilmington, N. C	48	51	54	61.	70	77	80	78	74	64	55	49	63	18
Atlanta, Ga	43	48	52	62	69	76	78	76	72	62	52	45	61	18
Augusta, Ga	48	52	56	64	72	79	82	80	75	65	55	49	65	18
Mobile, Ala	51	56	60	67	74	81	83	81	78	68	57	53	67	18
English stations.														
Lancaster	36	39	44	50	50	57	60	58	52	48	44	41	48	2
Blackpool	37	40	43	48	52	59	61	60	56	49	45	40	50	3
Bolton	35	38	40	46	51	57	59	58	54	47	42	38	47	4
Macclesfield	34	37	39	46	50	57	58	57	53	45	41	37	46	4
Northwich	36	39	41	48	54	61	62	61	56	48	43	39	49	4
Buxton, Derby	33	36	37	41	47	53	56	56	52	44	40	36	44	6
Cheadle, Stafford	34	36	40	42	48	54	57	57	53	45	41	37	45	6
Indian stations.														
Bombay	73	75	79	83	85	83	81	80	80	81	79	76	80	44
Dacca	66	70	78	82	83	83	83	83	83	80	74	68	78	21-23
Madras	76	77	81	85	87	87	85	84	84	81	78	76	82	31

TABLE VIII.—*Monthly mean precipitation, in inches and hundredths.*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Length of record.
New Bedford, Mass	3.90	3.82	4.17	3.96	3.95	3.15	3.36	4.28	3.48	3.98	4.31	4.11	46.31	75
Woods Hole, Mass	3.70	3.70	4.90	4.20	3.00	2.70	3.30	4.10	3.40	4.10	4.80	3.30	44.90	13
Newport, R. I.	4.88	4.58	6.50	4.81	2.75	3.28	3.67	3.65	3.10	3.88	5.50	3.96	49.97	8
New London, Conn	4.85	3.98	4.74	3.67	3.59	3.16	4.02	4.70	3.85	4.44	4.07	3.46	47.50	25
Oswego. N. Y.	3.10	2.50	2.80	2.10	2.50	3.30	3.40	2.50	2.80	3.40	3.30	3.40	35.00	22
Utica, N. Y.	3.34	3.10	3.07	2.83	3.63	4.28	4.62	3.71	3.54	3.44	3.85	3.68	43.09	38
Charlotte, N. C.	5.20	4.60	5.20	3.70	4.70	4.70	5.90	5.50	3.20	3.60	3.20	4.40	53.60	14
Wilmington, N. C.	3.90	3.20	4.20	3.10	4.20	5.90	7.20	7.80	6.70	4.10	2.60	3.20	56.30	21
Atlanta, Ga.	6.30	5.30	6.50	3.70	3.80	4.40	4.70	4.40	4.20	2.50	4.00	4.90	54.50	14
Augusta, Ga.	4.50	3.80	5.40	3.60	3.40	4.20	5.20	4.80	3.70	2.70	3.20	3.60	48.10	22
Mobile, Ala.	5.00	4.70	7.40	5.00	4.50	6.10	6.50	6.60	5.10	3.10	4.40	4.50	62.70	21
English stations.														
Lancaster	2.20	4.58	2.23	1.06	2.60	2.47	3.20	4.58	2.72	4.88	2.92	3.80	36.88	2
Blackpool	2.16	2.51	1.31	1.15	2.80	2.16	2.85	4.63	3.40	4.48	2.72	2.94	33.05	3½
Bolton	2.88	3.44	1.96	1.72	2.88	2.84	3.72	5.40	3.82	4.68	3.52	5.00	41.82	4
Macclesfield	2.79	2.45	1.71	1.37	3.38	2.81	3.31	4.19	2.27	3.77	2.35	3.56	33.62	4
Northwich	2.06	2.08	1.18	1.48	2.60	3.05	2.80	3.83	2.30	3.46	2.18	3.29	30.83	4
Buxton	3.19	6.10	3.93	2.60	3.42	4.23	5.32	5.52	5.00	5.20	5.88	5.80	56.14	6
Cheadle	2.22	3.48	2.38	2.02	2.27	3.24	4.28	4.48	3.42	3.61	3.27	3.82	37.99	6
Indian stations.														
Bombay	0.12	0.01	0.00	0.04	0.53	20.45	24.12	12.83	9.65	2.02	0.49	0.05	70.30	30
Dacca	0.36	0.99	2.55	5.74	9.08	13.29	13.07	12.35	9.72	5.17	0.72	0.19	73.23	40–42
Madras	0.92	0.27	0.40	6.04	2.16	2.11	3.86	4.50	4.70	11.02	13.47	5.29	49.34	78

TABLE IX.—*Monthly mean cloudiness (scale of 0–10).*

Stations.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.	Length of record.
New Bedford, Mass.	5.0	5.0	6.0	5.2	4.8	4.9	5.1	5.0	4.8	4.7	5.2	5.4	5.1	5
Woods Hole, Mass.	5.9	5.8	5.3	5.1	5.4	5.1	4.8	5.1	5.1	5.6	5.5	5.7	5.4	3
Newport, R. I.	5.3	5.0	5.8	5.5	5.4	4.7	5.2	4.8	5.0	4.8	5.5	5.5	5.2	8
New London, Conn.	5.3	5.0	5.3	5.2	5.1	4.8	4.8	4.8	4.8	4.9	5.1	5.2	5.0	24
Oswego, N. Y.	8.2	7.6	6.9	5.6	5.4	5.0	4.7	4.8	5.1	6.5	8.0	8.5	6.4	24
Utica, N. Y.	7.8	7.8	7.6	6.3	5.5	4.7	5.2	5.1	4.9	6.4	7.3	8.0	6.4	3½
Charlotte, N. C.	5.7	5.3	5.0	4.6	4.8	5.1	5.2	5.2	4.8	3.9	4.3	4.8	4.9	16
Wilmington, N. C.	5.3	5.4	4.8	4.4	4.6	5.0	5.2	5.3	4.8	4.0	4.5	4.8	4.8	24
Atlanta, Ga.	5.7	5.5	4.7	4.4	4.5	5.1	5.2	5.4	4.4	3.8	4.5	5.1	4.9	16
Augusta, Ga.	5.1	5.1	4.6	4.2	4.2	4.8	4.9	5.2	4.6	3.5	4.4	4.7	4.6	24
Mobile, Ala.	5.5	5.4	4.9	4.8	4.4	5.1	5.3	5.0	4.5	3.7	4.4	5.2	4.8	24
English stations.														
Lancaster	7.4	4.8	2.6	5.5	6.3	6.4	7.3	6.9	7.0	.....	7.8	.....	.....	1
Blackpool	6.3	7.7	4.9	5.8	5.1	4.9	5.2	6.2	6.4	6.5	7.9	7.6	6.4	*3
Bolton	7.7	8.3	6.0	6.0	7.0	6.9	7.6	7.8	6.7	7.8	8.5	8.1	7.4	4
Macclesfield	7.8	7.2	6.0	5.4	6.8	6.3	7.8	7.5	6.4	6.9	8.1	7.4	7.0	4
Northwich	6.4	6.0	4.0	4.1	6.0	5.4	5.7	6.6	5.9	5.7	6.8	6.5	5.8	2½
Buxton †	7.4	8.1	7.4	7.0	6.5	7.3	7.3	6.8	6.9	7.1	7.2	7.6	7.2	6
Cheadle †	7.2	7.2	6.3	6.6	6.0	6.5	7.0	6.5	6.4	6.6	7.0	7.6	6.8	6
Indian stations.														
Bombay	1.5	1.3	1.7	2.2	3.9	7.9	9.1	8.8	7.4	4.2	2.2	1.8	4.3	44
Dacca	1.6	1.8	3.1	3.9	5.3	7.6	7.9	7.8	6.8	4.1	2.2	1.4	4.5	22
Madras	3.9	2.6	2.4	2.9	3.9	6.4	7.1	6.5	6.1	6.1	6.1	5.3	4.9	21

* Record broken. † Mean of 9 a. m. and 9 p. m. observations.

Plate I.—Curves typical of the relative humidity (1878–1880) at the places named.

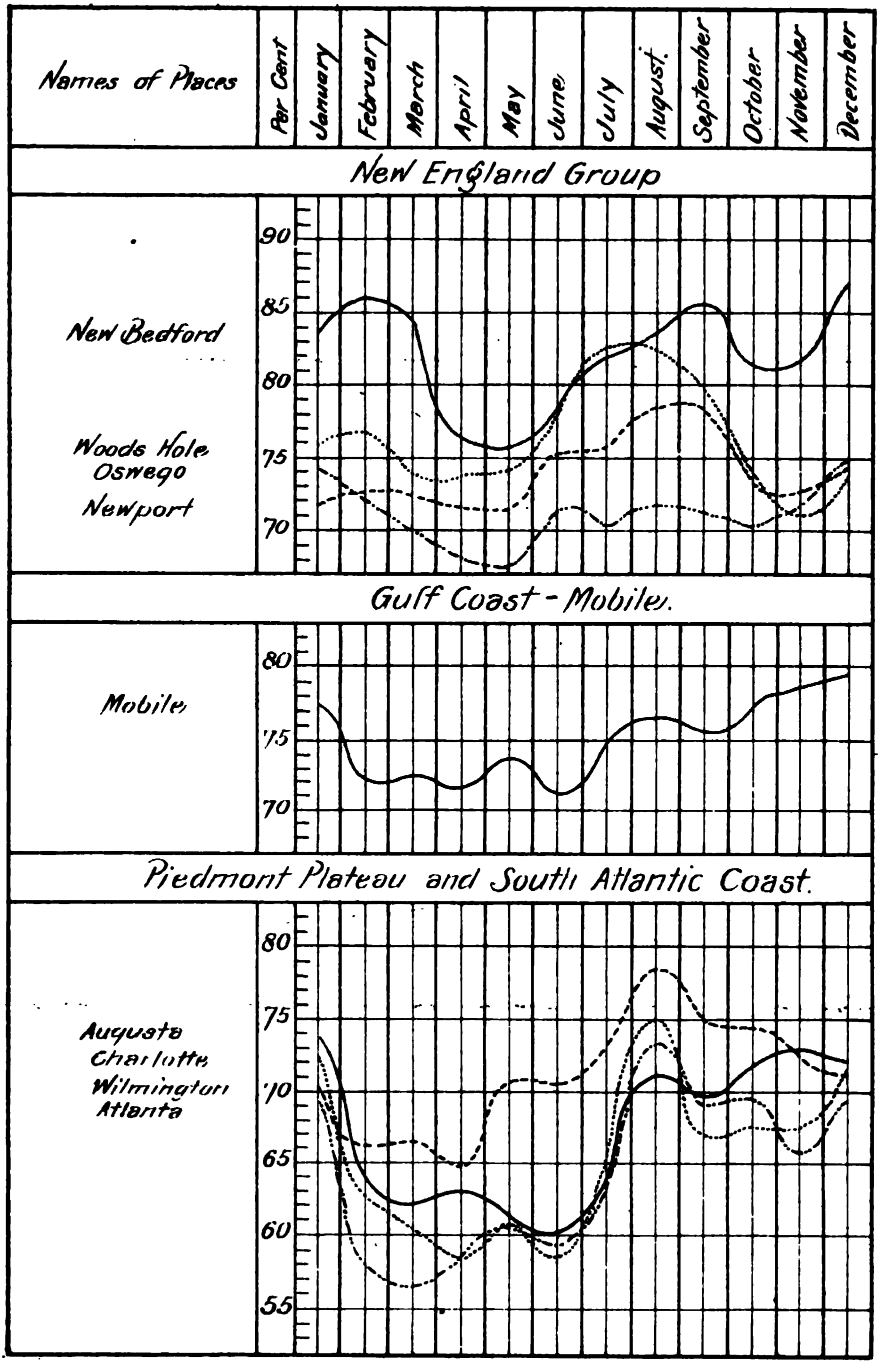
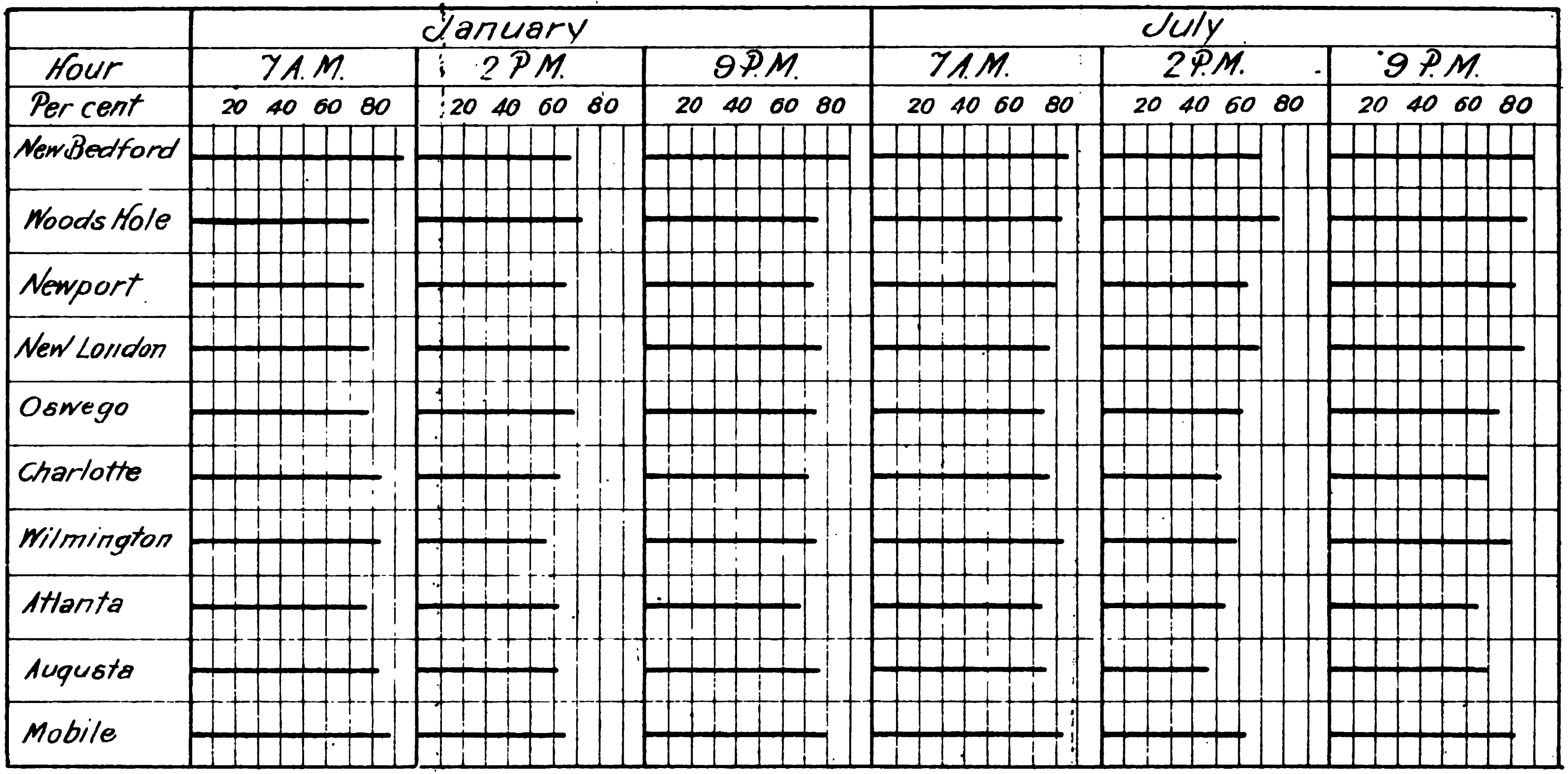
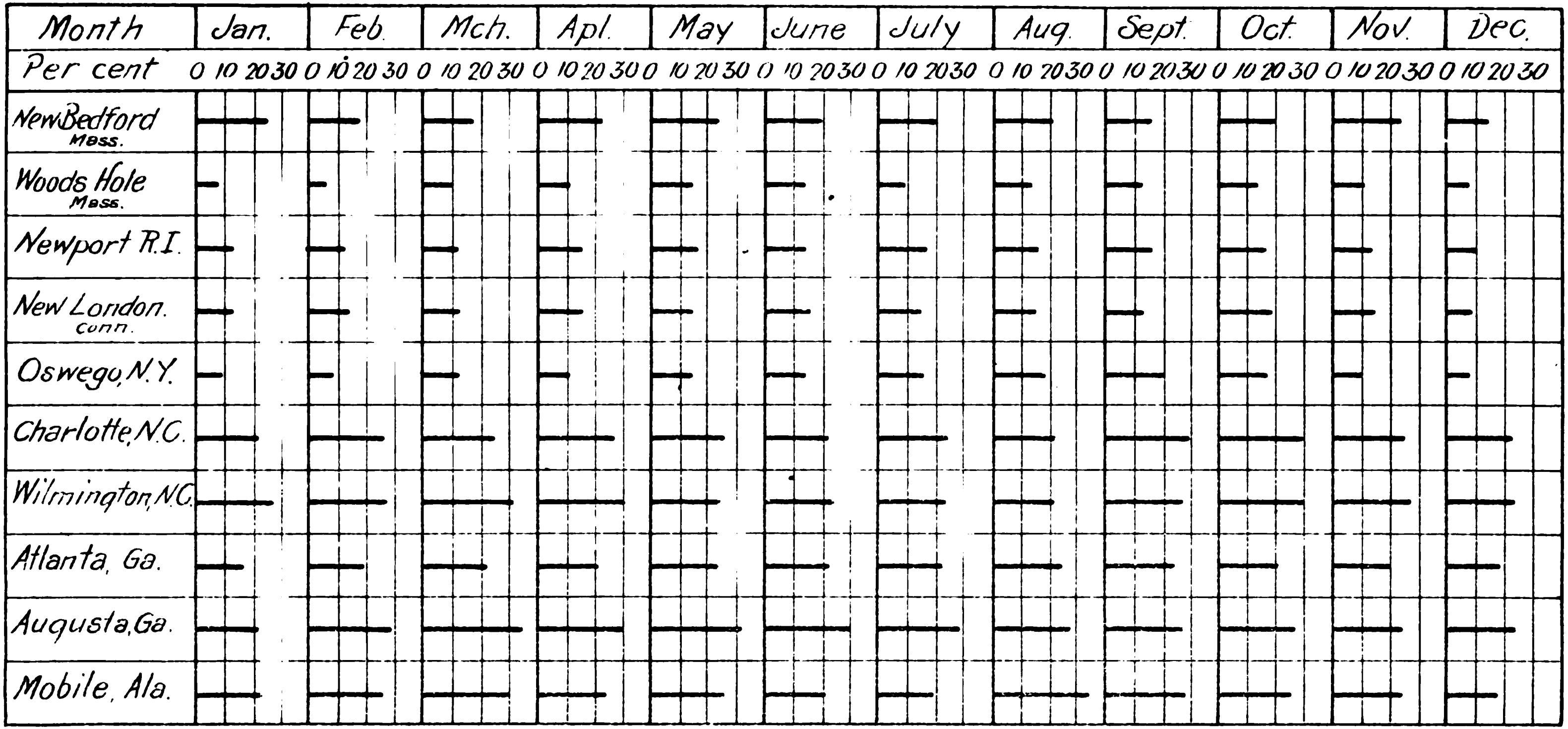


Plate II.—Relative humidity at 7 a. m., 2 and 9 p. m. for January and July.



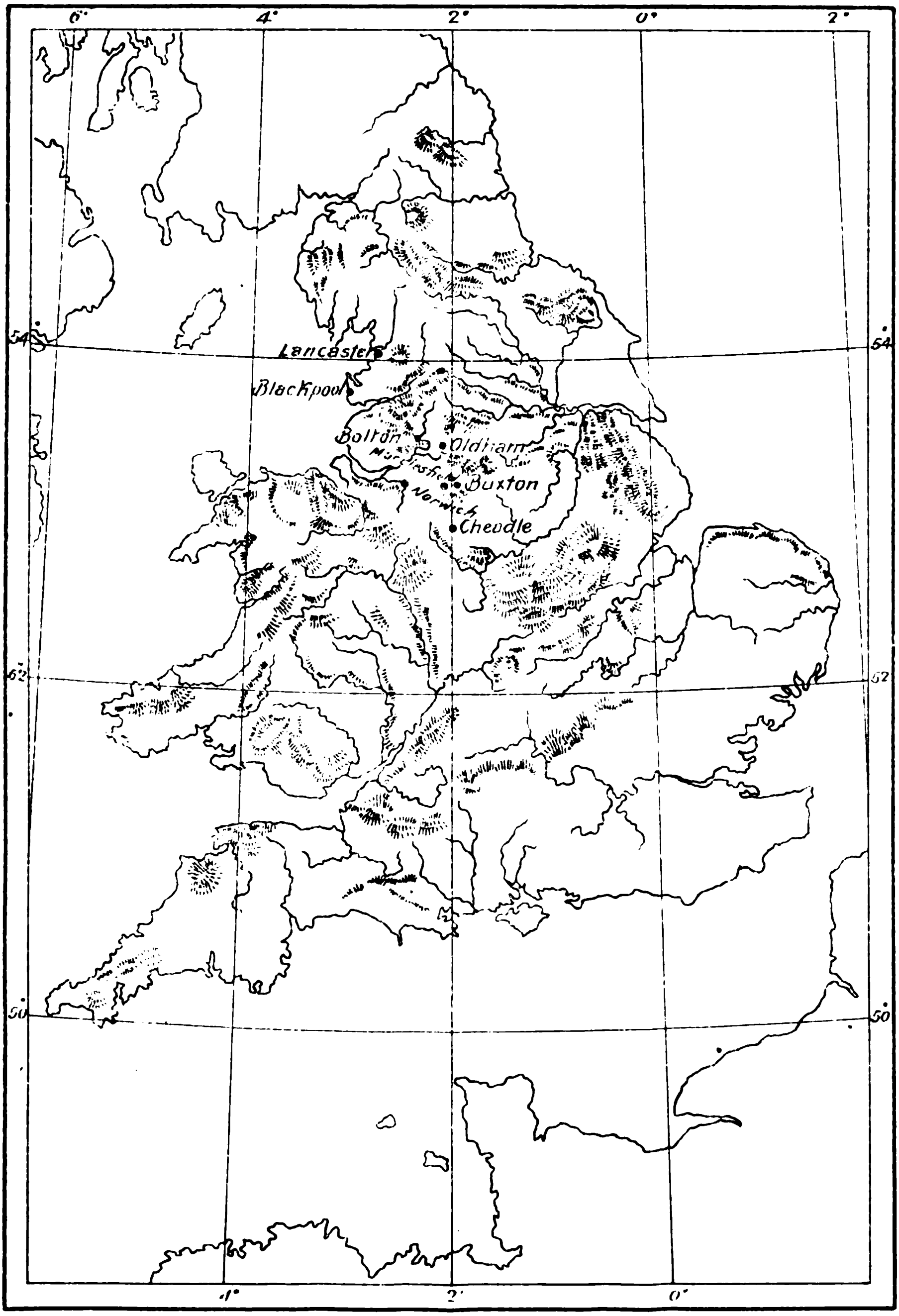
The percentage of relative humidity at the hours named is proportional to the length of the heavy black horizontal line.

Plate III.—Diurnal variation of relative humidity.



The data from which this chart has been made are given in Table III. The heavy black horizontal lines indicate the daily range in humidity; in other words, the difference between the highest average humidity and the lowest average humidity. If the average at 7 a. m. is 80 per cent and at 2 p. m. 60 per cent, the average daily range would be 20 per cent The ranges are drawn to scale, each vertical section representing 10 per cent.

Plate IV.—Sketch map of English stations.



BULLETIN NO. 20. W. B. NO. 114.

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STORMS, STORM TRACKS,

AND

WEATHER FORECASTING.

Prepared under direction of WILLIS L. MOORE, Chief of Weather Bureau,

BY

FRANK H. BIGELOW,

Professor of Meteorology.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1897.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF CHIEF OF WEATHER BUREAU,
Washington, D. C. July 11, 1896.

SIR: I have the honor to submit herewith a bulletin by Prof. Frank H. Bigelow, of the Weather Bureau, entitled Storms, Storm Tracks, and Weather Forecasting.

Its purpose is to present the latest phases of the science of meteorology as regards practical forecasting of weather conditions. It is believed that the bulletin will be found of particular value to those engaged in teaching meteorology, and also to students of the subject. Furthermore, it is intended to be of assistance to the observers and other officials of the Weather Bureau, and, in so far as it treats of weather forecasting by months and generalizations on the same, it is recommended for their careful study, as the most lucid exposition so far presented for their information.

In order to foster an intelligent interest in some of the laws probably influencing the weather conditions, Professor Bigelow has added a brief statement of the relations that appear to exist between the solar magnetic energy and the pressures and temperatures of the Northwest. It is not intended by him to put this forth as a finished working system for forecasting, but only as an illustration of the knowledge that is being developed in this interesting and important field of research.

I respectfully recommend that it be published as a bulletin of the Weather Bureau.

Very respectfully,

WILLIS L. MOORE,
Chief of Bureau.

HON. J. STERLING MORTON,
Secretary of Agriculture.

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STORMS, STORM TRACKS, AND WEATHER FORECASTING.

INTRODUCTION.

COOPERATION OF THE PRESS WITH THE WEATHER BUREAU—HOW TO CONSTRUCT A DAILY WEATHER MAP.

The policy of the Department of Agriculture is to place before the people of the United States as much practical scientific information as possible. This knowledge really belongs to the people, inasmuch as they sustain the necessary expense of collecting the data upon which investigations are made. When valuable results are acquired, the wide publication of the same, in as simple language as is consistent with the subject, is a primary duty.

The Assistant Secretary of the Department of Agriculture, Dr. Charles W. Dabney, jr., is especially in charge of this popular distribution of scientific knowledge, and has enjoined upon the bureaus and divisions of the Department the duty of cooperating in this direction.

The Weather Bureau, which has charge of the collection and dissemination of all proper information regarding the ever-changing weather conditions, so directly affecting the wealth and health of the people, has, in accordance with the policy of the Department, had this bulletin prepared, which, it is thought, contains valuable information on the subject.

The very important cooperation that the press is giving to the distribution of weather information in this and other communities is most gratifying. While it is possible for the Government to publish a comparatively small number of the daily weather maps of a large size, and to distribute these by messenger or by mail, it is nevertheless plain that main reliance must be placed upon the daily press for this purpose. Since a practical way has been found to make clear small reproductions of the large map, the necessity for the Government map is somewhat modified, because the general points of the current weather conditions are displayed sufficiently well for all common purposes on the reduced scale. Moreover, the advantage is all with the papers in reaching larger numbers of people.

Reports are being constantly received of an increasing interest in the daily weather map on the part of many persons who have been attracted by the press reproductions, and very often these are accompanied by the expression of the wish that they could understand the meaning of the lines a little better. The proportion of readers who perceive the significance of the lines showing temperature and pressure of the air, as they change from map to map in their location, is already great, and it is thought that with a little care and effort nearly every one who can read may also comprehend the daily map, at least approximately.

It is like learning a new language, and at first costs some labor, but when once the symbols are understood there is a pleasure in reading the same that compensates for the intellectual work expended. "How to construct a daily weather map" is therefore addressed to those who have not quite mastered the symbols and the lines on the map, and to those who have not yet attempted to look into it at all. If some one in each family will take the trouble to follow the directions that are given herewith, it will not be long before every member can take an interest in this branch of the Government service.

It is well known that the forecasters of the Weather Bureau often make mistakes in their efforts to interpret the probable changes in these lines for a day or two ahead, and that in consequence they are subject to criticism by the public for their failures. On comparing these criticisms from different portions of the country, it is seen that the people who best understand the difficulties of the art of forecasting are most just in their criticisms, and that generally the press has been fair in its statements. This is no doubt in a measure due to the advantage that the reporters of the press have in their frequent visits to the central and local offices of the Weather Bureau, by which they are more in touch with the details of the work itself. In the same way, the more familiar the people of any locality are with the way of making the forecasts, the more considerate they are of failures to reach perfection. It is therefore desired that every one should know as much as possible on this subject, to the end that criticisms arising from impatience and partial knowledge may be corrected. Meteorology as a science is in some respects still in its elementary stages of growth, and there is much to be discovered about the laws controlling the atmosphere. The wonder is that so imperfect a science can have already contributed so much to the benefit and protection of the people. It is to be hoped that maps of artistic merit may become regular features of the journalism of the large cities of the United States.

This bulletin gives for each month of the year the meteorological normal conditions and the prevailing features of the storm tracks characteristic of the month, with such remarks as will direct attention to the main types of weather to be expected during the month; also general remarks on forecasting, embracing long-range forecasting.

The first thing to understand is how to draw in the lines that appear on the map. About 142 observations, 8 a. m. and 8 p. m. daily, are received from different points of the country, taken all at the same moment of time for a given map. For the 8 a. m. map they are telegraphed in and received at Washington between 8.30 and 9 o'clock. These are entered on charts, the forecaster reads the meaning, and the forecasts are out by 10 or 10.30 o'clock. On Chart 1 only 22 of these places are laid down, so as to avoid crowding on the reduced scale.

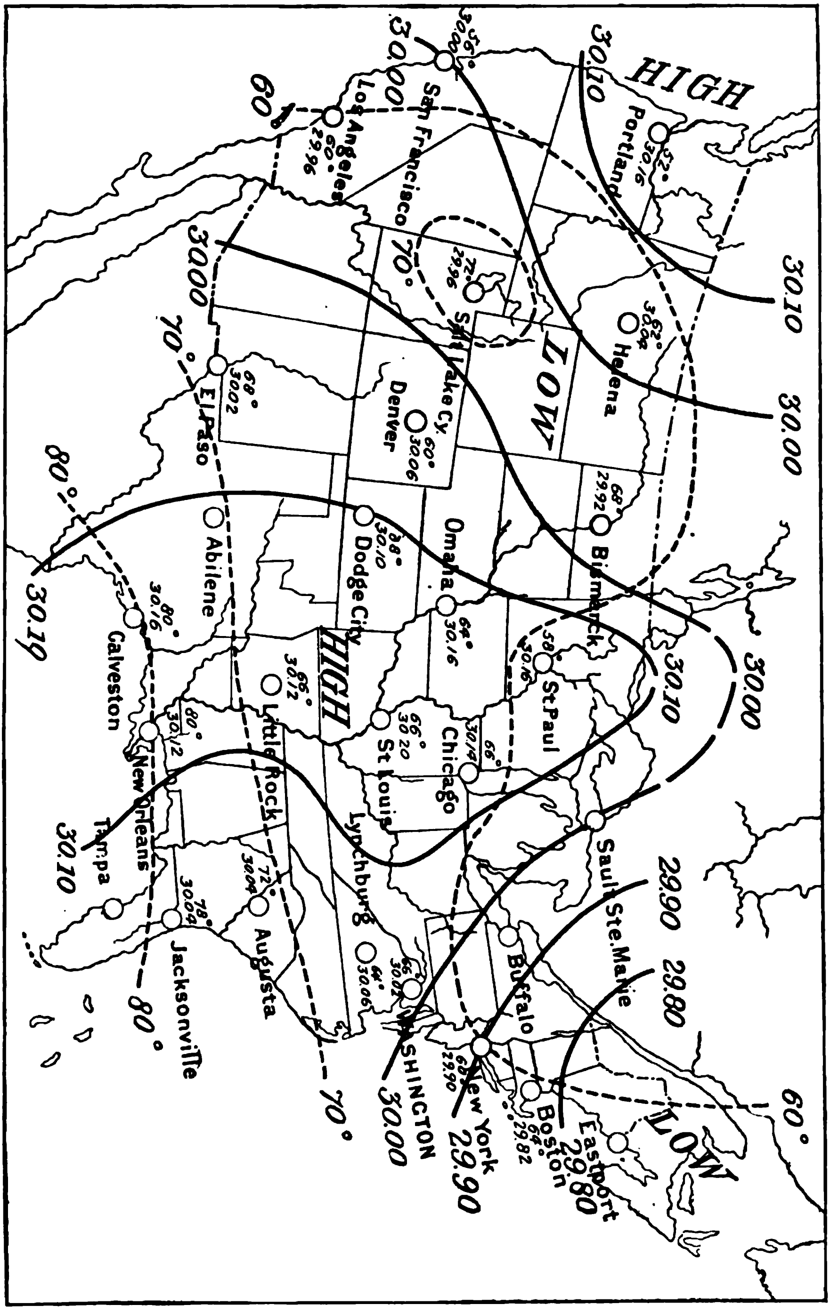

Chart 1.—Map of Thursday, August 1, 1895, 8 a. m.

For illustrating the mode of drawing the lines the Washington map of Thursday, August 1, 1895, 8 a. m., is selected. Against each of the 22 cities are written two sets of figures, the upper giving the temperature and the lower the pressure of the air at 8 o'clock in the morning of August 1. Thus the temperature at Boston is 64° and the pressure 29.82 inches; at New York, 60° and 29.90 inches. Toward the west the time of the observation is earlier in the morning; that is, in the Mississippi Valley the observer reads his instrument at 7 o'clock, local time; on the Rocky Mountain slope, at 6 o'clock, and on the Pacific Coast, at 5 o'clock, so that all the observers may read at the same moment. Cooperation is, therefore, the peculiar feature of the operations of the service. On looking over the map the simplest question to ask is, Where do the same temperatures prevail, and where are the pressures just alike? It is evidently helpful to the eye to draw a line through the places where the same conditions exist, and it is most convenient to select the even 10° differences, and the even 10-inch differences for such connecting lines. That is, dotted lines are drawn through all places having the temperatures 60°, 70°, 80°, and solid lines through the places having the pressures 29.90 inches, 30 inches, 30.10 inches, barometric pressure. Now, in order to do this it becomes necessary to interpolate the spaces. It is seen that the temperature at Galveston and New Orleans is 80°, and a line can be drawn through these, but for Jacksonville the temperature is only 78°, and the 80° line must run a little south of it to allow for the drop from 80° to 78° in going northward. For the 70° line the process is as follows: At El Paso the temperature is 68°, and evidently the 70° line must lie between El Paso and the 80° line at intervals of 2° on the El Paso side and 10° on the Galveston side; near Little Rock, 4° on one side and 10° on the south side; near Lynchburg, 6° on the north side and 10° on the south side. The intervals 2 to 10, 4 to 10, 6 to 10 are the interpolations referred to, and by a little practice can be very rapidly performed. In the case of the 60° line the process is the same, and it runs through Los Angeles, between Portland and Helena, 8 to 2; between Bismarck and St. Paul, 8 to 2; between St. Paul and Chicago, 2 to 6; north of Washington, through New York, and west of Boston. These dotted lines of equal temperature are called *isotherms*.

In a similar manner interpolate for the pressure lines. Thus the 30.10-inch line runs between El Paso and Galveston, 8 to 6; through Dodge City, west of Omaha, between Bismarck and St. Paul, 18 to 6; returns southward between Chicago and Washington, 4 to 8; between St. Louis and Lynchburg, 10 to 6; between Little Rock and Augusta, 2 to 6, and between New Orleans and Jacksonville, 2 to 6. The 30-inch line starts between Los Angeles and El Paso, 4 to 2, and passes between Salt Lake City and Denver, 4 to 6, just east of Bismarck; follows the general curve of the 30.10-inch line and passes between Washington and New York, 2 to 10. Another 30-inch line passes through San Francisco, between Helena and Bismarck, 4 to 8. Another 30.10-inch line passes between Portland and Helena, 6 to 6. A 29.90-inch line passes through New York City and a 29.80-inch line just north of Boston. These lines should always be drawn so as to harmonize with each other, making a system of curves that grade into each other by easy changes. Such lines of equal pressure are called *isobars.*

These details are given in the hope that readers will take the trouble to construct, from the map given for the purpose, a little map for themselves by way of practice. Take some semitransparent paper and trace the base lines, the boundaries, and the rivers, and locate the 22 cities. Copy against each city the figures for the temperature and the pressure, and then interpolate the dotted lines for temperature and the solid lines for pressure. The figures in Chart 1 are taken from the first and third columns of the table as printed on the right-hand side of each large weather map issued by the Weather Bureau. If anyone will copy the base map and these figures for a few days in succession, and then plat in the isotherms and the isobars, and will thus watch the variable positions on the maps from day to day of the lines of the same name, a clear idea of the fundamental features of the weather map will soon be secured.

In addition to these lines, symbols for wind and weather are used: For wind, an arrow on the station circle pointing the way the wind blows, and for weather—clear, a fine-line circle; cloudy, a full-shaded circle; partly cloudy, a half-shaded circle; raining, the letter R, and snowing, the letter S, at the station. A general rain area is shaded on the map.

Near the center of an area of high pressure above 30 inches is placed the word "high," and near the center of a region of pressure less than 30 inches is placed the word "low." A low-pressure system is called a storm or a cyclone, and the winds blow around the center in the opposite direction to the hands of a watch as one looks on the watch lying upon the map with the face up. The high-pressure system is called an anticyclone, and the winds blow around its center in the general direction of the hands of a watch, though in a less distinct manner than in the cyclone. The winds always blow down the gradient from the high to the low, from the anticyclone to the cyclone.

These are the chief features on any weather map, so far as its construction goes. Those who wish to learn to understand the meaning of the same in regard to the resulting weather conditions should construct them for themselves, until familiar with the details. Then they should carefully compare the maps from day to day and observe the differences that have taken place in twenty-four hours, in forty-eight hours, and in seventy-two hours. The easiest way to do this is to cut out the press map every day and lay the successive maps in a column, above one another, so that the eye may take in at a glance the changes that have been going on. A short practice in this manner will enable one to follow the storms as they pass from west to east, and will also soon give the ability to judge from the maps what the weather conditions are likely to be during the following twenty-four hours.

WEATHER FORECASTING, BY MONTHS.

AUGUST.

MEAN STORM TRACKS—DISTRICTS OF LOCAL ORIGIN—AUGUST STORMS AND TRACKS.

The first impression of any student on approaching the practical use of the weather maps, as they present their seemingly endless forms and combinations of the temperature and pressure lines, is one of confusion. This feeling is also sure to be attended by one of discouragement, and probably the impluse to abandon the task of seeking an underlying plan is more powerful to many persons than the incentive, which depends upon curiosity, to know what it all really means.

The storms of the United States follow, however, year after year a series of tracks, not capricious, but related to each other by very well-defined laws.

The positions of these tracks have been determined carefully for the United States by studies made in the forecast division of the Bureau, on the long series of maps that have been made during the past twenty years. The line that the central point of a high area or that the center of a storm makes in passing over the country from west to east is laid down on individual charts, these are collected on a group chart, and from this the average line pursued can be readily described. Chart 2 shows the general result of a study of tracks of storms in the United States. It indicates that, in general, there are two sets of lines running west and east, one set over the northwestern boundary, the Lake region, and the St. Lawrence Valley; the other set over the middle Rocky Mountain districts and the Gulf States. Each of these is double, with one for the highs and one for the lows. Furthermore, there are lines crossing from the main tracks to join them together, showing how storms pass from one to the other. On the chart the heavy lines all belong to the tracks of the highs and the lighter lines to the lows. Let us trace them somewhat in detail. A high reaching the California coast may cross the mountains near Salt Lake and then pass directly over the belt of the Gulf States to the Florida coast; or it may move farther northward, cross the Rocky Mountains in the State of Washington, up the Columbia River Valley, then turn east, and finally reach the Gulf of St. Lawrence. We may speak of the lower track as the *southern circuit* and the upper as the *northern circuit*. These are located where they are by the laws of general circulation of the atmosphere and configuration of the North American continent. This movement of the highs from the middle Pacific coast to Florida or to the Gulf of St. Lawrence is confined to the summer half of the year—April to September, inclusive.

In the winter months, on the other hand, the source of the highs is different, though they reach the same terminals. In the months October to March, inclusive, many highs enter the United States near the one hundred and fifteenth meridian and flow south along the Rocky

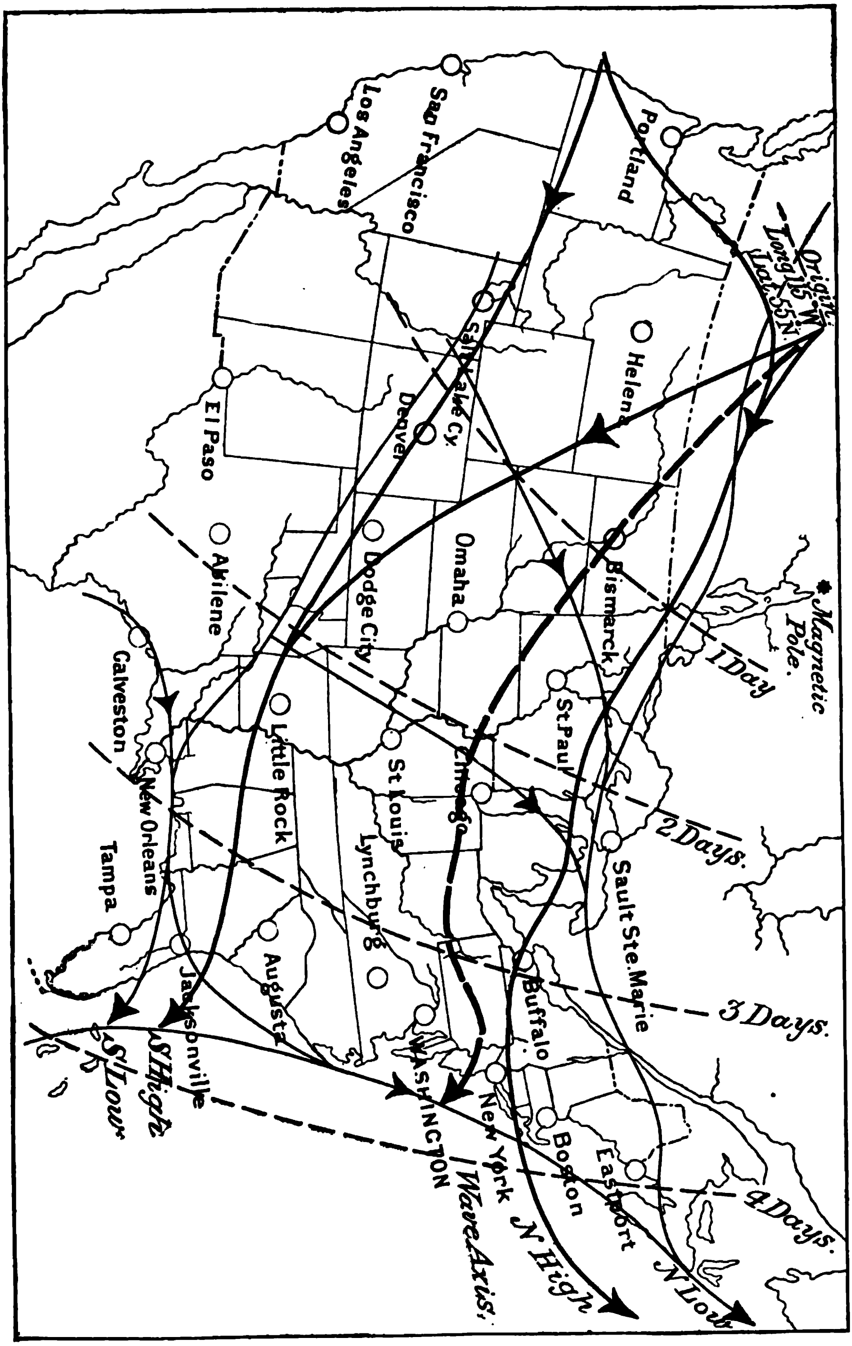

Chart 2.—Mean tracks of storms in the United States.

Mountain slope into the southern circuit, and thus reach the South Carolina coast; or else they turn more abruptly eastward and move in the northern circuit over the Lakes to Newfoundland. The chief difficulty in the art of forecasting is to decide from the current lines on a map which of these paths will be pursued, and then the probable rate at which the movement will take place.

Chart 3 shows the nine districts that have been adopted in the study of the local origin of storms, the total number of storms that formed in each district for the ten years 1884–1893, and the average track that the storms passed over in moving from their place of origin to the Gulf of St. Lawrence.

The storms or centers of low pressure are strictly dependent for their life upon the highs, being, in a word, only the natural mode of the disintegration of the highs, and the raising of the air by force against gravitation, from lower to higher levels in the atmosphere. The highs have two main places of entry into the United States, but the lows have at least nine places of generation, or entrance upon our territory. First, a majority of our storms originate in the region north of Montana, in Alberta, and move eastward, while some make a loop southward over the mountain slope before regaining the northern circuit; second, a number appear on the North Pacific coast and eventually disappear over the Gulf of St. Lawrence, if they live so long; third, others form on the northern Rocky Mountain plateau and follow the same track as the North Pacific coast storms; fourth, a large number from near Colorado are apparently produced by the very high mountainous elevations of that district, and usually join the northern circuit near the Great Lakes; fifth, the lower lands of Texas, catching the Gulf winds and moisture, generate a few storms each year, and these move northeastward over the central valleys to the lower lake region, whence they proceed down the St. Lawrence Valley, but a few storms come in from the extreme west of the Gulf of Mexico, enter the southern circuit near the mouth of the Mississippi River, whence they usually advance along the Gulf Coast and then near the Atlantic Coast to join the great track to the north and east of New England; sixth, the West Indian storms, or hurricanes, come in from the southeast near the twenty-fifth parallel, recurve northward and hug the Atlantic coast line to Nova Scotia, some other storms, however, appear in the east Gulf States; seventh, a few are first seen on the South Pacific coast; eighth, others begin on the South Atlantic coast and are strictly coast storms; ninth, some storm formations occur in the central valleys. These are the main tracks, though, of course, many instances occur in which it is hard to satisfactorily classify them. It is seen that wherever the storms may arise, whether in Alberta, on the Pacific Coast, in Colorado, Texas, Mexico, or in the West Indian region, they all try, sooner or later, to leave the United States in the neighborhood of New England. This is evidently a sufficient explanation of the very variable and the extremely harsh

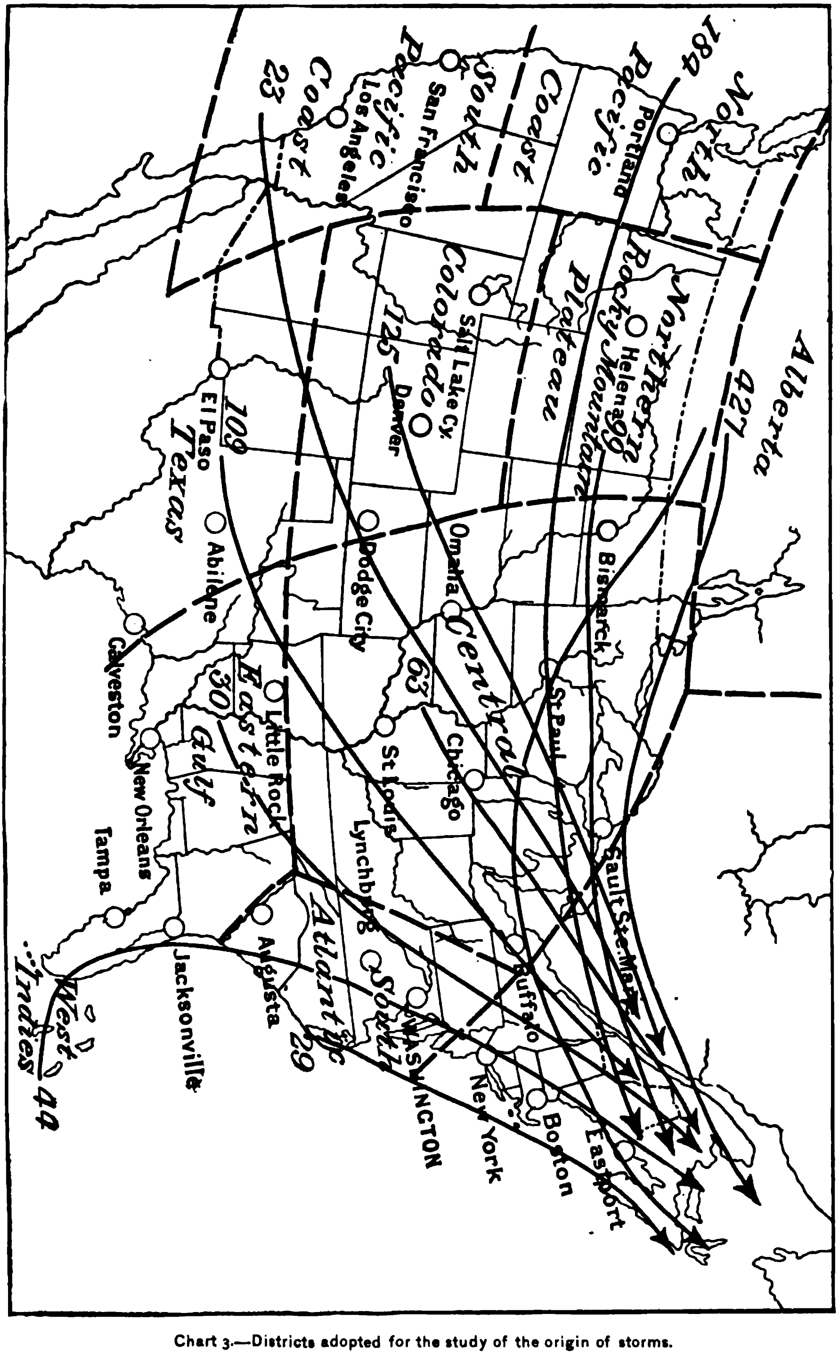

Chart 3.—Districts adopted for the study of the origin of storms.

weather that is so peculiarly the lot of that region. If all roads lead to Rome, all storms and weather tracks lead to New England.

There are seen on Chart 2 two other systems of lines, (1) those marked one day, two days, three days, four days, and (2) that marked wave axis. The former shows the average position of the storms that come in from the northwest on successive days, that is, after one day it will be found on the Rocky Mountain slope, in two days near the lower Missouri and Mississippi valleys, in three days near the Appalachians, in four days decidedly over the ocean. The latter shows the middle frontage of the cold waves as they come down from the northwest in the winter season.

The storms of August belong almost entirely to the Alberta, the Colorado, and the West Indian types. In ten years it was noted that 83 storms came into the field of the weather map in the month of August. Of these, 45 originated to the northward of Montana, or in the northwestern districts, and all of them moved eastward over the Lakes and the valley of the St. Lawrence to the ocean, a few of them dissipating on the way. More than half of the August storms begin and move along the northern circuit, like beads on a string, with great regularity. The breadth of the track covered by them is about 400 miles. This accounts for the fact that in the Northern States the alternation of warm and cool days takes place with wave-like regularity, while in the Southern States the temperature is almost uniform, though warm, week after week.

The next important place for August storms to come from is the State of Colorado, and it is found that in the same ten years 12 storms originated near there, moved northeast over the Lakes, joined the main branch in that district, and pursued their course eastward to the ocean. These Colorado storms in summer are apt to be accompanied by the warm wave that seems to set in at the eastern base of the Rocky Mountains and to gradually spread over the entire country to the Atlantic.

The third important system of storms are the hurricanes that arise in the trades of the Tropics, move westward to the Gulf of Mexico, curve up northward and enter the United States in the Lower Mississippi Valley, or skirt the coast districts, or else keep off the shore in the neighborhood of the Gulf Stream. These storms move in parabolic-shaped tracks, and spread over a very wide belt in the latitude of the Gulf States, east and west, whence comes the chief uncertainty in forecasting their approach to the coast of the United States. Eventually they advance to the same point of departure, the Gulf of St. Lawrence and Newfoundland.

Only 14 other storms were observed in the ten years 1884 to 1893, inclusive, scattered over the country in a very desultory way. August storms travel at the rate of 16 to 26 miles per hour, or about 500 miles a day. The question of the rainfall attending these storms is too large to consider, but it can be broadly stated that precipitation takes

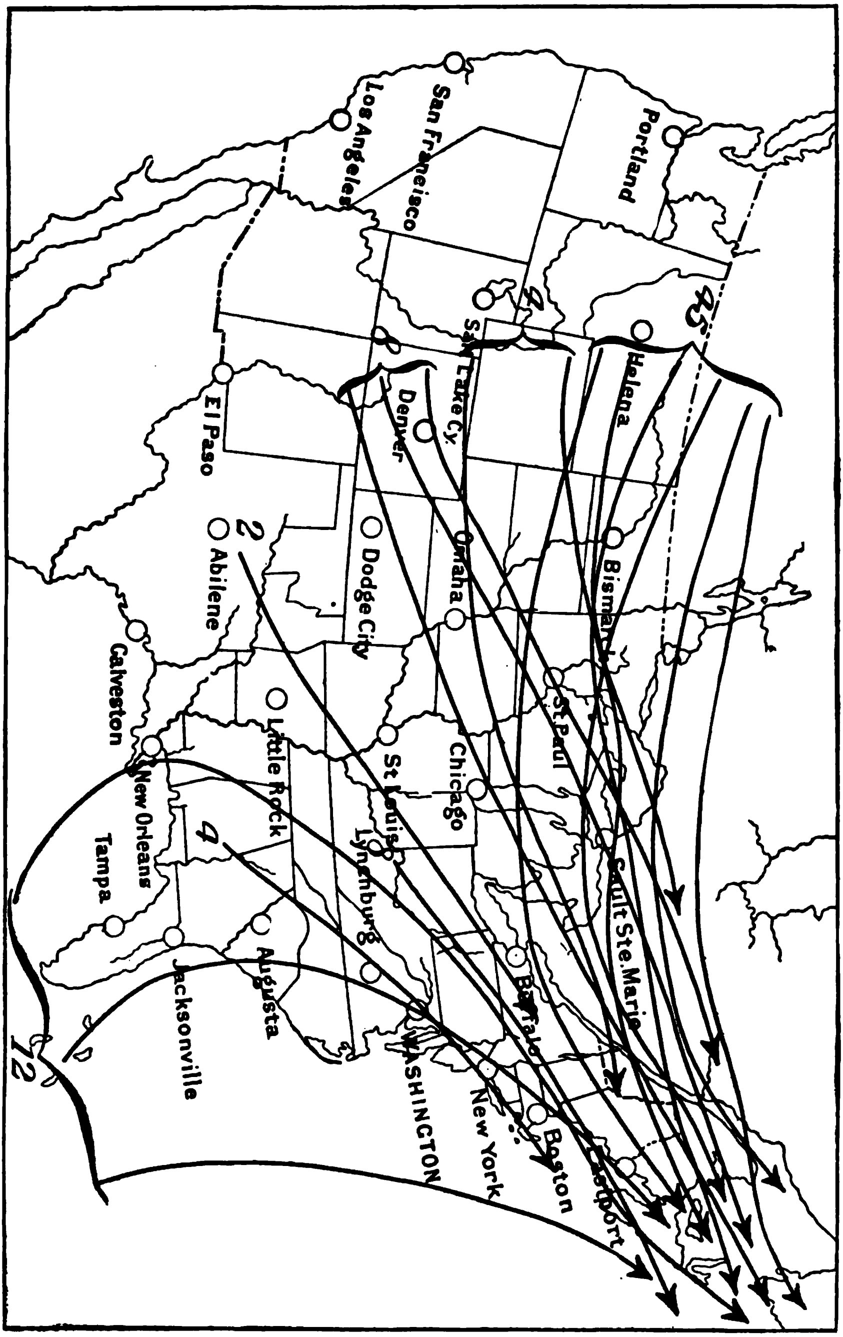

Chart 4.—Storm tracks for August.

place to the east and south of the storm center. Much of the rain in August is sporadic, in the form of thunderstorms, and these seem quite as ready to occur in connection with the high areas as in the low. This makes it much more difficult to satisfactorily forecast the time and place of these small local storms.

The months of August, September, and October make up the hurricane season, because tropical storms are most frequent during these months. Of the 12 hurricanes referred to, 5 first appeared near the Windward Islands. Two of these recurved east of the Florida peninsula, 2 disappeared over the Gulf of Mexico; 1 crossed Cuba and the Gulf of Mexico in 1886, and upon reaching the Texas coast, on the 20th, destroyed Indianola; passing thence northwest this storm dissipated over the southern Rocky Mountain region during the 21st and 23d. Two cyclones apparently originated near the Bahamas, one of which recurved northeastward off the North Carolina coast, and the other reached the Louisiana coast and moved thence northeastward over the lower Mississippi and Ohio valleys, New England, and Nova Scotia. The remaining 5 cyclones appeared north of the West Indies and east of the seventieth meridian. One of these reached the North Carolina coast August 23, 1893, skirted the middle Atlantic coast, and crossed New England. Another was the destructive storm which devastated the south Atlantic coast on the 27th and 28th of August, 1893. The mechanism of these destructive storms, which is very interesting, is given under September.

The hot waves of August come from two sources. They originate in a mass of heated air on the Rocky Mountain plains and gradually move eastward from thence. On the other hand, a high area settling over the south Atlantic and Gulf States has the effect of charging the stagnant air with heat, as if the eastward circulation in the upper air was suspended for quite long intervals of time.

SEPTEMBER.

SEPTEMBER STORMS—MECHANISM OF A HURRICANE.

One of the chief interests, aside from the value they have in respect to forecasting, in the study of charts of storm tracks consists in comparing them month with month, in order to observe the changes that take place with the progress of the seasons. It is shown on Chart 4 under August that the summer storms, in the majority of cases, originate in three places, in Alberta, Colorado, and the West Indies. On the other hand, in September Chart 5 indicates that they arise in at least six places. We have one set of storms generating in Alberta, of which 39 were observed in ten years; there were 13 noted that entered the North Pacific coast of the United States; next, 5 were observed to commence their activity on the northern plateau of the Rocky Mountains; also, 7 developed over the isolated plateau of Colorado; 8 appeared on the west coast of the Gulf of Mexico or in Texas; finally, 7 tropical hurricanes came in from the West Indies.

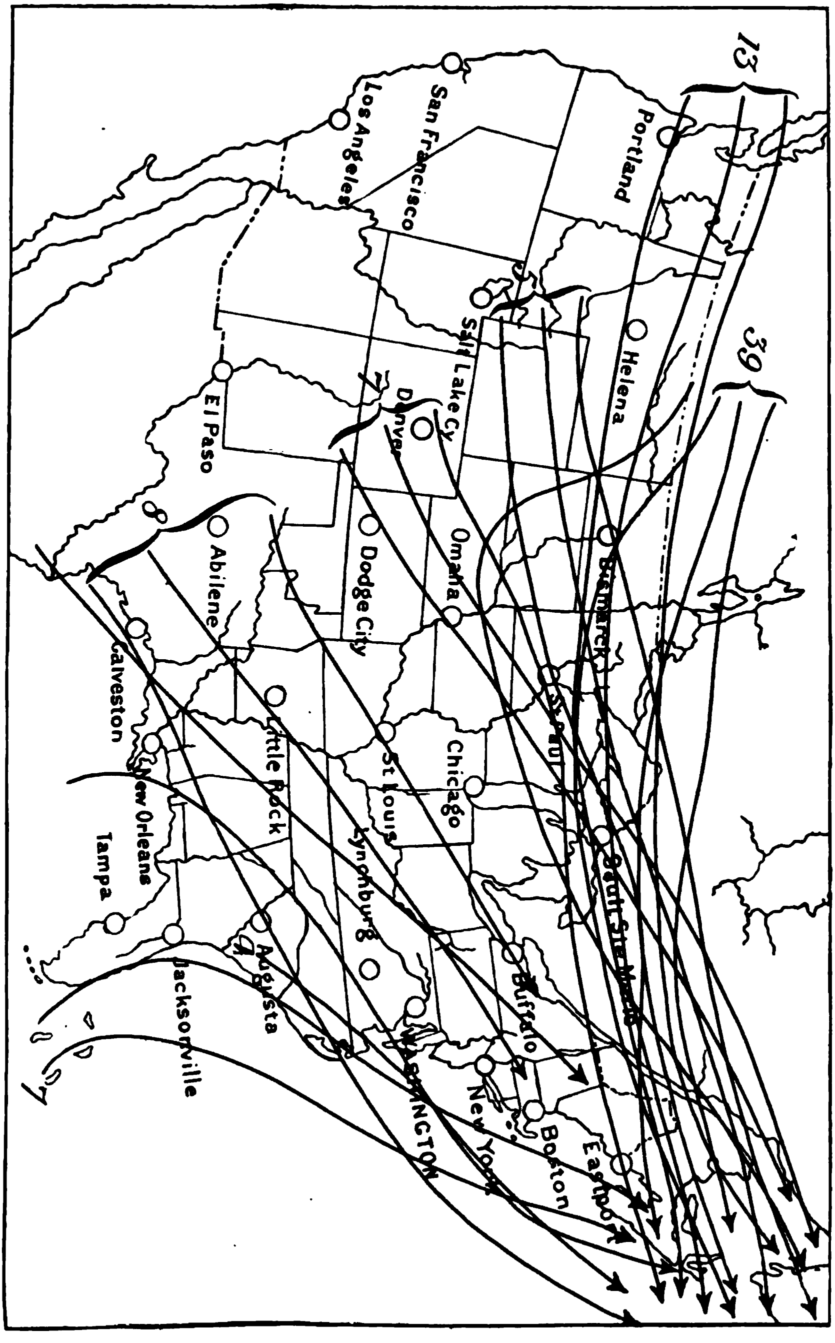

Chart 5.—Storm tracks for September.

These all pursued their paths to the Gulf of St. Lawrence, in the neighborhood of which they left the field of observation. The Alberta storms run along the northern boundary of the United States in the northwest, cross the Lake region, and advance down the St. Lawrence Valley, reaching the Gulf of St. Lawrence in about three days. It will be observed that these tracks have a strong tendency to loop down near the beginning of their paths over the Rocky Mountain slope into North Dakota and South Dakota, whence they recover the main track in the neighborhood of Lake Superior. The North Pacific storms, those from Wyoming and Idaho, as well as the Colorado storms, in twenty-four hours find themselves on the main track in the Lake region, whence they go to the Gulf of St. Lawrence. These four groups belong very clearly to one family, and have their rise on the northward side of the great high-pressure belt that extends around the globe in about latitude 30° to 35°, except where it is deflected by the continents. In the United States this belt leaves the Atlantic coast near South Carolina, but it enters this country in northern California or Oregon nearly 10° farther north. The deflection thus observed is no doubt largely due to the elevations of the Rocky Mountain districts.

On the southern side of the high belt another system of storms generates, because the air of this belt must flow off on both sides, south as well as north, though the quantity returned to the southward is less than that to the northward. Thus, we find here eight west Gulf of Mexico and Texas storms, which usually advance to the Gulf of St. Lawrence over the Atlantic States; also we have the West Indian storms, which are developed farther east, in the calm zone of the doldrums, move westward awhile in the westerly tropical current, recurve on the western edge of the great Atlantic anticyclone, hugging the periphery of the same, and also skirt the Atlantic coast, unless by the obstruction of a high they enter the Gulf States before they recurve. The erratic movements of the west Gulf and the east Gulf storms consist in their effort to break through the high-pressure belt. It is during this passage, when they are most vigorously fed, that they attain the destructive violence so often noted in the Southern States.

September is the middle of the hurricane season for the West Indies. In the China seas the season covers the same months—August, September, and October; in the Bay of Bengal there are, however, two seasons—April to June and October to November; in the Arabian Sea there are the same two seasons as in the Bay of Bengal; in the South Indian Ocean the height of the season is in January, February, and March. These differences depend upon the relations of the land and water in the Tropics, where such storms begin.

In the ten years examined the seven West Indian hurricanes recurved on the average in the longitude of the Florida peninsula. The destructive storm of September 1–7, 1888, did not recurve, but passed over Cuba westward to the Mexican coast. In 1894, September 21–30, the storm recurved, causing serious devastation along the Atlantic coast. The primary cause for recurving or not is in the existence or nonexistence of a high area over the eastern Atlantic States. The cyclone follows in behind the high, and if this moves off to sea, opening a trough after it, the hurricane moves northward in the ordinary track. If the high hangs persistently on the coast, the cyclone is deflected far to the west before it can recurve, in which case it is likely to show very destructive qualities on the west side of the Gulf of Mexico. If rain falls freely before the hurricane comes to land, it is likely to die out; if the downpour begins after reaching land, it is probable that a long, vigorous march is yet before it.

There is much discussion in meteorological circles about the exact cause of the production of hurricanes in certain months only, and also regarding the mechanism of the whirling monsters, opinion not yet having settled upon any complete theory regarding these points. Some of the facts may, however, be reviewed, and the most probable form of the movement of the winds deduced from them. At the time of the hurricane season, August to October, the large areas of calm, sultry, and rainy atmosphere, called the doldrums, stretch from the west coast of Africa, near Senegambia, to the north coast of South America, near Guiana, in their northernmost latitudes. At the same season of the year the great Atlantic high area, on account of the heating of the continents, seems to have contracted its boundaries, and to be confined to the ocean, leaving, as it were, channels near the land, and especially on the American side. After having once started, these hurricanes hang along the border of the great ocean high, skirt its southern edge, gradually turn north on the western side, or recurve, and still following the outline of this high proceed off to the northeast, and enter the regular mid-latitude storm track. Now, the significance of the calm belt of the doldrums and the adjacent high is that the air building up in the high as it runs down feeds any vortex or whirl that may have been started along its edge, and thus continues to supply it for the many days that these violent storms are observed to last.

Some students have claimed that the tendency of the warm, moist doldrum air to rise up is the first cause of producing these cyclones. But there is one very difficult objection to overcome before this view can be established. Air will rise by convection only when the difference of temperature is considerable between the rising column of air and the adjacent regions; yet in hurricanes this difference of temperature is not observed.

Now, on examining the maps for the isobars, it is almost always seen that the lower isobar, marking out the edge of the great ocean high, has a loop or sort of pocket, by the bending down of the line, and in this the whirl begins. In the autumn, as the sun is moving southward, the impulse of the air is to follow it, and it may well be that the smooth isobar lines stretch out fingers toward the equator, into the doldrum calm, making a pocket of lower pressure, and that herein the whirling vortex begins its course. Its future, dependent, as has been said, upon the performance of the high area in opening up a passage near the American coast, is merely the sucking in of the air from the high area, practically regardless of temperature, the rain also being a secondary phenomenon.

As to the hurricane itself when once set in motion, we have more definite information. The approach of a hurricane is usually indicated by a long swell on the ocean, propagated to great distances and forewarning the observer by two or three days. A faint rise in the barometer is indicated before the gradual fall that may become very pronounced at the center; fine wisps of cirrus clouds are first seen which surround the center to the distance of 200 miles, the air is calm and sultry, but this is gradually supplanted by a gentle breeze, and later the wind increases to a gale, the clouds become matted, the sea rough, rain falls, and the winds are gusty and dangerous as the vortex core comes on. Here is the indescribable tempest, dealing destruction, impressing the imagination with its wild exhibition of the forces of nature, the flashes of lightning, the torrents of rain, the cooler air, all the elements in an uproar, which indicate the close approach of the center. In the midst of this turmoil there is a sudden pause, the winds almost cease, the sky clears, the air is cool, the waves, however, rage in great turbulence. This is the eye of the storm, the core of the vortex, and is, perhaps, 20 miles in diameter, one-thirtieth of the whole cyclone. The respite is brief and is soon followed by the abrupt renewal of the violent wind and rain, but now coming from the opposite direction, and the storm passes off with the several features following each other in the reverse order.

By the laws of vortex motion the winds approach the center in spirals, the circular and the centrifugal movements increasing every moment. At the core, in the walls of the columnar vortex, the air circles about the calm central part, gradually rising upward to the cloud stratum, just above the inflowing disk. Here the air flows out suddenly on all sides, the circular motion decreasing, cooling by expansion, causing a great thin sheet of rain 200 or 300 miles from the center. At this distance the vortex sheet turns up suddenly, not down as usually stated, and discharges the expended vortex matter into the high upper currents of the atmosphere. If one holds a saucer of ordinary shape up and looks at it from the under side, it will not give a very incorrect idea of the general shape of this thin vortex sheet as it turns up and discharges at the edges. Over the whole underside of it is the rain cloud, in the center the ring core and the calm part.

The feeding wind lines are more nearly parallel to the ground than the upper discharge lines, but they all form a simple columnar vortex of unusual configuration. The clear sky at the center is as if a hole were pierced in the saucer, through which the undisturbed air above alone was visible. There is probably no feature of nature more interesting to study than a hurricane, however the feelings of the observer may be affected by the experience of one at hand.

OCTOBER.

THE THREE PRIMARY DIVISIONS OF THE METEOROLOGICAL YEAR—STORM TRACKS AND WEATHER CONDITIONS FOR OCTOBER—FROST FORMATION IN THE AUTUMN.

The calendar year is capable of division into three parts as regards its meteorological conditions, and to a very considerable extent storms and other features of the weather have characteristics that closely resemble each other within these periods of time. They refer to the months (1) December, January, February, and March; (2) April, May, October, and November; (3) June, July, August, and September. The first group comprises the conditions that are dominated by low temperatures, the third those that are ruled by high temperatures, and the second the transition in October and November from hot to cold and April and May from cold to hot weather. The winter months are signalized by very turbulent circulation of the atmosphere; the rate of eastward motion is at a maximum; the storm tracks are spread all over the United States, so far disregarding their primary paths that these are nearly unavailable for classification, great alternations of temperature and pressure, cold waves, high winds, and violent precipitation being the regular features. On the other hand, in the summer months the circulation of the air is very feeble; the eastward drift is slow and illy defined; the tracks are for the most part confined to the northern border, except in the case of hurricanes and coast storms; the temperature is generally high, with small fluctuations in it, and the pressure for wind circulation small; instead of gales, only violent local storms and thunderstorms are observed.

The two pairs of transition months differ from each other in a marked degree. Thus, in the autumn, with the advance of the colder season, a sort of crispness is discovered in the air, the succession of highs and lows across the country is so well defined as to approach most closely to the typical or ideal circulation, the arrangement of all the surface winds and the precipitation is very simple, and forecasting is comparatively easy. This condition lasts until it is gradually merged into the violent outbursts of the winter, by which the chain of waves is distorted from a simple succession. In the spring the transition from cold to warm weather is one of relaxation, and an increasing feebleness or uncertainty of action takes place; many storm conditions fail to fully develop; the eastward drift ceases at times; stagnant movements of storm areas often prevail; the unlooked-for happens in consequence of a sudden intrusion of a winter storm from the north, as if the supply of cold had not yet been exhausted, and forecasting is in its most perplexing and tantalizing state.

October, then, is the first of the months to feel the approach of colder atmospheric conditions in the northern hemisphere, and if the charts are examined for their mean annual conditions it will be seen that the first symptoms of continental action in North America are present, by means of which the large permanent low pressure that covers the Arctic regions in summer is broken up into two permanent lows in winter, one central in the extreme north of the Atlantic Ocean, near Iceland, and the other in the north of the Pacific Ocean, near the Aleutian Islands. This is done by the building of a belt of high pressure over the British Possessions in the neighborhood of the Mackenzie River, which finally spreads so as to join an advancing high pressure belt from Siberia. Hence, in the United States, the high belt crosses the Gulf States to the northern Rocky Mountain slope, near Wyoming, whence one branch proceeds westward across the mountains to the Pacific Ocean, and the other branch extends just eastward of the great mountain range parallel with it to the Arctic Ocean. The Rocky Mountain region, by its lofty elevations of 1 or 2 miles, especially as a plateau, has a very great influence upon the generation of storms in the United States. Unfortunately, this region is practically unexplored by the refined processes known to science, and there is great need of planting some strong observatories in this region in the interests of meteorology, well equipped to observe the action of the sun, by means of the spectroscope, the photograph, the magnetic needle, and the telescope, in addition to the physical instruments employed by meteorologists. It is the center or heart of the circulation of the atmosphere for the United States, and yet its structure is little known at the present time.

The compilation of all the storm tracks for the month of October for the successive years shows, as in other months, that the same centers of origination prevail, the mean tracks and the number proceeding from a definite locality being given on Chart 6. It is seen that 36 storms commenced their eastward march from the district covered by Alberta, Saskatchewan Valley, and Assiniboia, or generally to the northward of Montana, whence they passed eastward over the Lake region to the Gulf of St. Lawrence; 12 set out from the northern Rocky Mountain plateau, and 11 from the middle plateau region, the former of which may be called the Yellowstone Park group and the latter the Colorado group, both of which joined the main track in the Lake region. Farther south 4 storms began in New Mexico or northwestern Texas, the tracks generally running up the Ohio Valley to the Gulf of St. Lawrence. Here we have 63 storms generating on the edge of the high plateau region of the Rocky Mountains in elevations of 5,000 to 9,000 feet above the sea level.

On the other hand, there are systems of sea-level storms whose origin is in very different physical conditions. Thus, from the North Pacific coast 18 storms entered the United States, and 3 from the South Pacific coast, the former joining the main track as soon as the mountains were

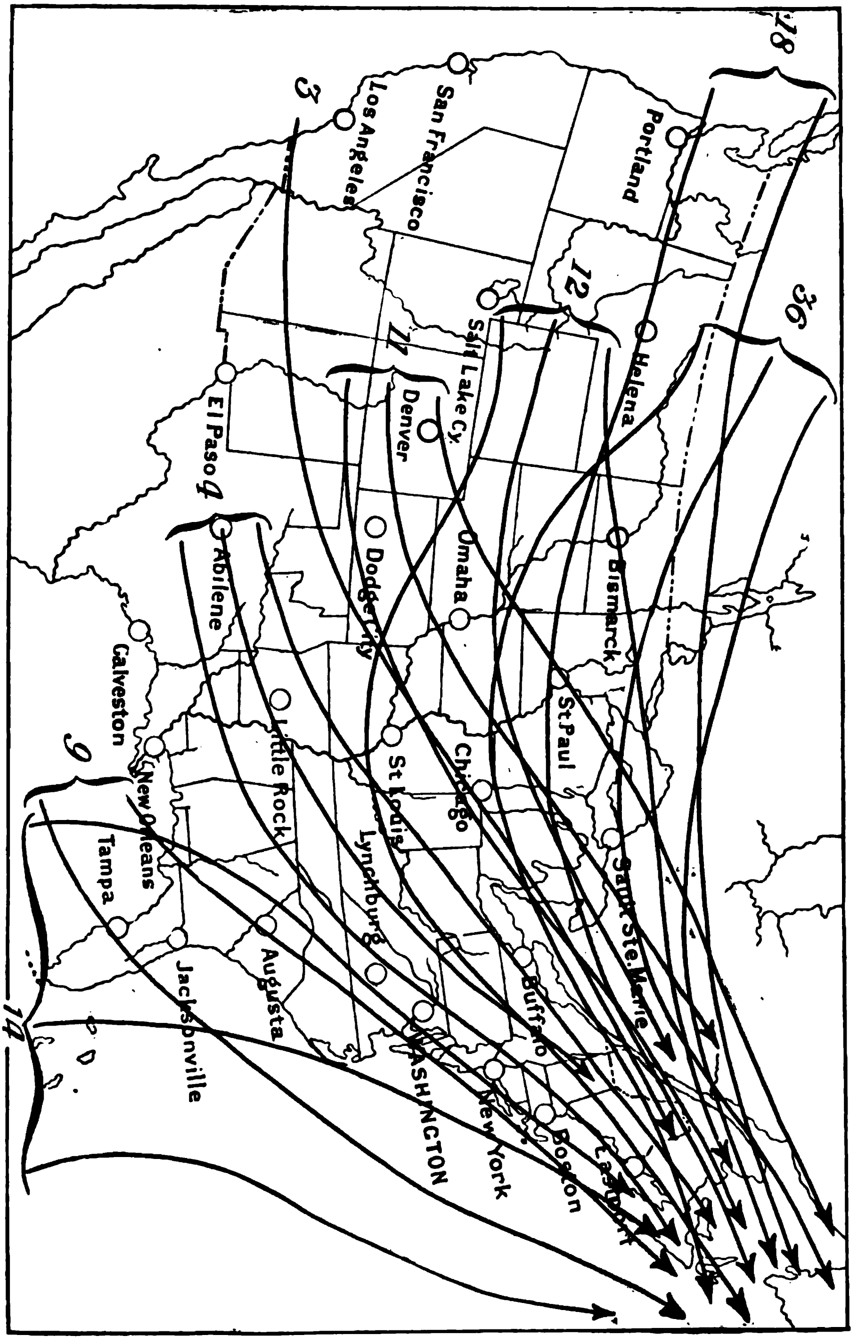

Chart 6.—Storm tracks for October.

crossed, the latter usually pursuing a track leading across the Gulf States; furthermore, there were 9 storms coming in from the Gulf of Mexico or Gulf States, and 14 West Indian hurricanes, whose tracks lay closely along the Atlantic coast. Hence, it is found that 41 storms originated at sea level and among conditions dominated by water areas. If we generalize, it may be concluded that six-tenths of our storms in October owe their origin to an elevated plateau region and four-tenths to ocean influences.

The true causes of the production of storms are so far from being understood that beyond this brief statement of the facts little that is settled can be advanced. If a similar comparison of storms originating at high elevations and at sea level be carried out for the twelve months, and covering a period of ten years, it appears that about 760 storms were generated at these high levels in the United States and about 383 at sea level; 67 per cent are therefore due to mountain regions, reaching into the high strata, and 33 per cent to ocean areas.

It is a singular fact that nearly all the observations upon which theoretical analysis has been based were made at low levels, because the facilities attendant upon civilized communities are found in the cities of the coast and the river valleys. Yet, on the other hand, the importance of attacking the problem in other quarters is very evident even from superficial considerations. When the demands of the highest science are considered, the argument for such observations is greatly strengthened.

The features of the October storms are so nearly normal that but few remarks are required concerning them. It may be noted, however, that of the storms commencing in the region north of Montana and the Dakotas, 11 dissipated in the Lake region and the remainder passed to the Atlantic Ocean north of the fortieth parallel, the average time required to reach the Gulf of St. Lawrence being about four days. The North Pacific storms have a tendency to keep well to the northward of the main track over the Lakes, after joining the Alberta path, and about two-thirds of them reach the Gulf of St. Lawrence.

October is one of the three months in which the West Indian hurricanes develop. On the international charts for ten years 1878–1887, inclusive, 16 occurred in August, 14 in September, and 17 in October, with 10 others outside these months; 14 were observed in October during the years 1884–1893. Of these, 5 came in from the Caribbean Sea, 3 appeared near the West Indian Islands, 4 apparently formed between the West Indies and Bermudas, and 2 over the eastern Gulf. The hurricane of October 11, 1887, recurved in the extreme western Gulf on the 17th, came ashore near New Orleans on the 19th, and passed over the Atlantic States to New Brunswick by the 21st; the storm of October 8, 1886, reached Louisiana on the 12th, and broke up over Arkansas on the 13th; that of October 10, 1885, crossed over Florida and the South Atlantic States, inclined westward to lower Michigan, and thence passed down the St. Lawrence River on the 14th; that of October 10, 1893, recurved just off the Florida peninsula, moved northward to South Carolina on the 13th, and advanced rapidly into Canada on the 14th and 15th; besides these the others enumerated kept pretty well offshore in the region of the Gulf Stream. It is to be remarked that the area of recurvature covered 30° in longitude, so that no very safe rule can be stated to aid the forecaster in making his analysis of existing conditions, but it is thought that the following rule is valuable:

> When a West India cyclone is moving westward in the longitude of eastern Cuba, and is north of that island, or is moving westward over Cuba or the western Caribbean Sea, it will recurve east of the south Atlantic coast of the United States when a high area occupies the northwest; and will probably cross the Gulf coast line when a low area occupies the northwest.—GARRIOTT.

The other storms of this month offer no special features, as they are generated in widely separated localities and finally march to the north Atlantic coast, unless earlier dissipated. The local storms are greatly diminished in frequency by October, owing to the colder temperature conditions prevailing from the lowest to the upper strata in the atmosphere. There has been but one group of tornadoes in five years, these occurring in Carolina within the loop of a low-pressure area; only 26 thunderstorms and 9 hailstorms were reported in the same period, no region showing any excess over the others in their production.

Heavy winds begin to prevail in certain places, Block Island and Hatteras leading, with winds above 50 miles per hour from the north and northeast; some of the Lake stations show heavy southwest winds; the stations on the Rocky Mountain slope, especially in Montana and the Dakotas, have severe northwest gales on the Great Plains, and on the Pacific Coast Fort Canby was visited by 15 wind storms from the south and west, with velocities above 50 miles per hour.

A word may properly be added regarding the formation of frost in the autumn, by which damage is often done to crops, especially the cranberry and tobacco, and to fruits and vegetables in the southern districts during the fall. Frost, as is well known, is caused by lowering the temperature of the air containing aqueous vapor till it reaches saturation, and then by further decrease of the temperature to the freezing point or below, when ice crystals of frost form on the vegetation. In the autumn this loss of heat in the air is due chiefly to a vigorous radiation from the ground, especially if the surface is dry, during the night, and it is favored by the conditions prevailing near the center of a high area, where the sky is clear, the wind very light, and the current of descending air comparatively steady. If the high drifts over a region where rain has fallen quite uniformly within twenty-four hours, the wetted surface tends to retard lowering of temperature, and will often screen a region from frost. The favorite protection, artificially available, is a dense layer of smoke from fires built on the windward side of the spot to be cared for, the effect of the stratum of smoke being to confine radiation to its upper layers and to conserve the surface heat, by which the temperature fall will be considerably diminished. It is known that the temperatures within cities, where observations for the regular Weather Bureau daily reports are generally made, run 10° to 15° higher than in the lowlands of the neighborhood where frosts are liable. This circumstance is kept fully in mind by the forecasters when issuing frost warnings for any district.

NOVEMBER.

STORM TRACKS—WHY THE WEATHER BECOMES DRIER IN THE AUTUMN—ISOBARS AND WIND LINES IN A TYPICAL CENTRAL STORM.

It was stated in the description of the storms for October that the period of the year covered by the months October and November is the one of transition from the warm to the cold season in the northern hemisphere. These two months so closely resemble each other that nearly all the statements made for October apply equally to November, and hence an opportunity will be taken to give a more minute account of the isobars and wind lines in a type storm filling the central valleys of the United States, instead of repeating the description for November.

In the count of the origin of storms for ten years as regards locality it was found that 63 storms commenced in the elevated regions of the United States in October and 56 in November, and that 44 and 35 storms in the respective months took their rise over or near ocean areas. Putting it all together for the two months, 134 originated over the land and 79 near or over the ocean, so that the percentage is 63 of the first and 37 of the second kind. All these storms tend to advance to the point of concentration—the Gulf of St. Lawrence—and about three-fourths of them reach Washington. There they are either dissipated, or pass out to sea in the general eastward drift of the atmosphere in this latitude. It is not very definitely known what proportion of the American storms arrived at the shores of Europe, but it is not very great; and it is certain that almost every one of the western storms breaks up in the interior of the Euro-Asian continent, instead of traversing it to the eastern coast of Asia.

It is generally observed by the public that these two months embrace some of the pleasantest weather of the year, which is characterized by cool, dry air, with quite a rapid succession of alternately warm and cool or cold days. The reason for this condition is easily understood. Storms and storm tracks have been discussed and little has been said of the high areas of pressure that accompany them. It would be more accurate to say that the lows or storms attend upon the highs and are really subservient to them. At any rate, looked at from a more general point of view, a procession of highs and lows, of cold and warm masses of air, marches across the country from west to east. The lows hang

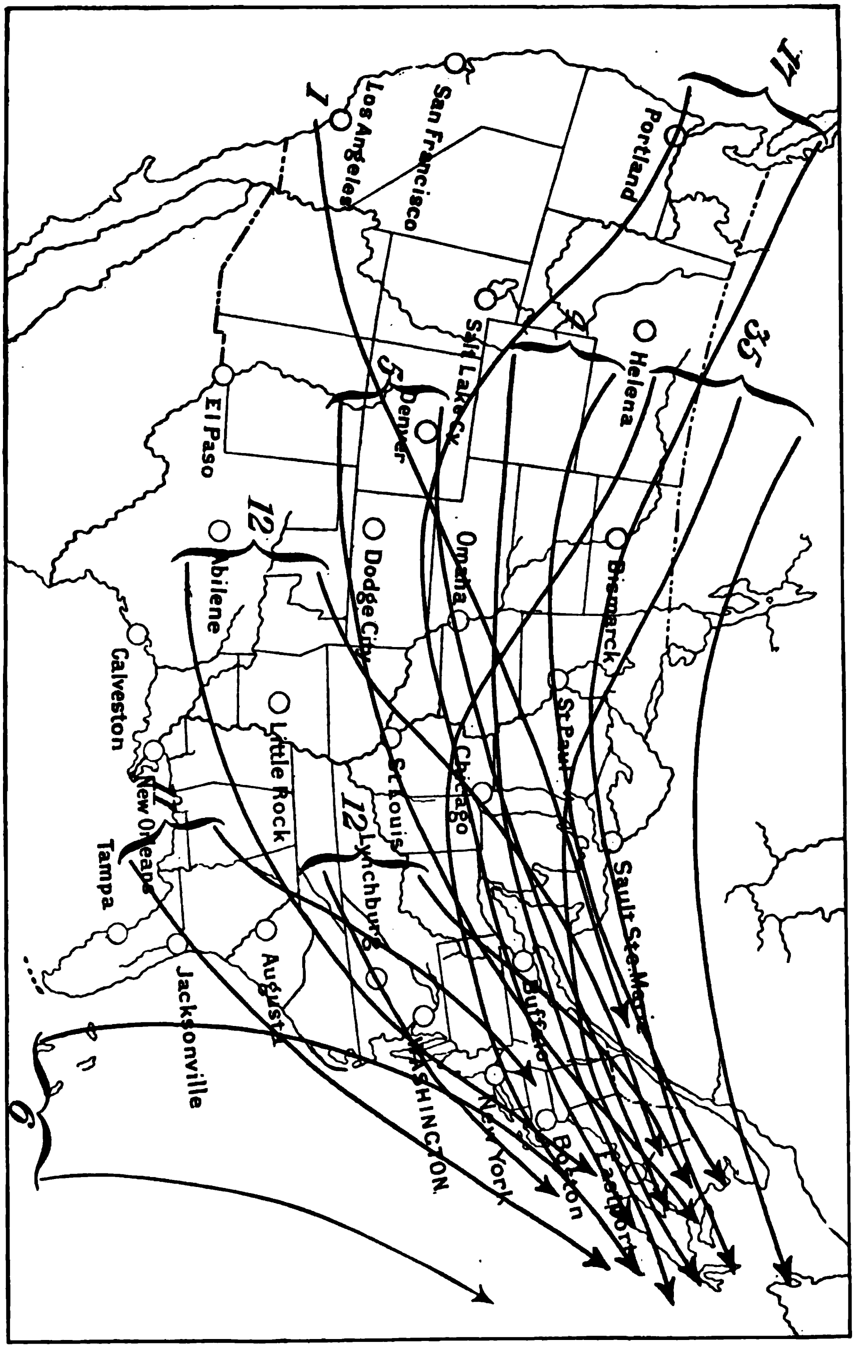

Chart 7.—Storm tracks for November.

along the borders of the highs in order to accomplish the courses marked out for them.

Now, in October and November the highs originate chiefly in the continental areas north of Montana and Dakota, more so as the winter comes on, though a number of course come in from the Pacific. At this season the continent has become quite dry, as the surface evaporation has been going on rapidly since summer, and the supply from the ocean has greatly diminished in consequence of the fact that the atmosphere tends to descend from the higher strata upon the continent, and to blow thence outward upon the ocean. In other months, when the land is warmer than the water, the circulation is from the ocean to the land, and this brings in moisture with the air to keep the ground full of water near the surface. The dry highs are like sponges, ready to suck up by evaporation all surface water, but when this supply fails then the original dryness of the air is maintained as the winds blow over the country.

Furthermore, the general lowering of the temperature of the atmosphere at this season, owing to the withdrawal of the sun to the southern hemisphere, is unfavorable for the air in the lower strata to retain much aqueous vapor in suspension. If the temperature of the air is 86° F., with barometer near 30 inches, it can hold about 25 grams of water per cubic meter before saturation takes place, but if the temperature falls to 50° it can sustain only 7 grams, and if to 14° only 2 grams. Now, on inspecting the maps it is seen that in the morning we are dealing with temperatures of 30° to 50° F., and therefore dry air can take up only 3 to 7 grams of water in the cubic meter. The consequence of these two causes is to produce dry weather, and this will continue as long as the continental cooling keeps the air, on the whole, blowing toward the oceans, or as long as great high areas of dry air fill our central regions. The statistics show that the Middle and South Atlantic States, the Gulf States, the Ohio and Mississippi valleys are very dry. On the other hand, the Lake regions and New England have a large number of rainy days, the precipitation, however, being very light for the most part.

Further inspection of the maps of the Weather Bureau discloses the fact that during these two months the storms that pass over the main track, along the Lakes and the River St. Lawrence, are well formed, even strongly developed, as the high winds on the Lakes and the New England coast testify. Yet they often pass over their entire course of three days' duration almost perfectly dry.

There may be a little rain or snow in the Lake region near the center of the storm, or even in the rear of it, but no general precipitation occurs, such as the formation of isobars and isotherms and the directions of the wind suggest and would certainly produce at other seasons of the year. The dryness has been explained, but one deduction must not be omitted. The convectional theory of storms holds that the energy

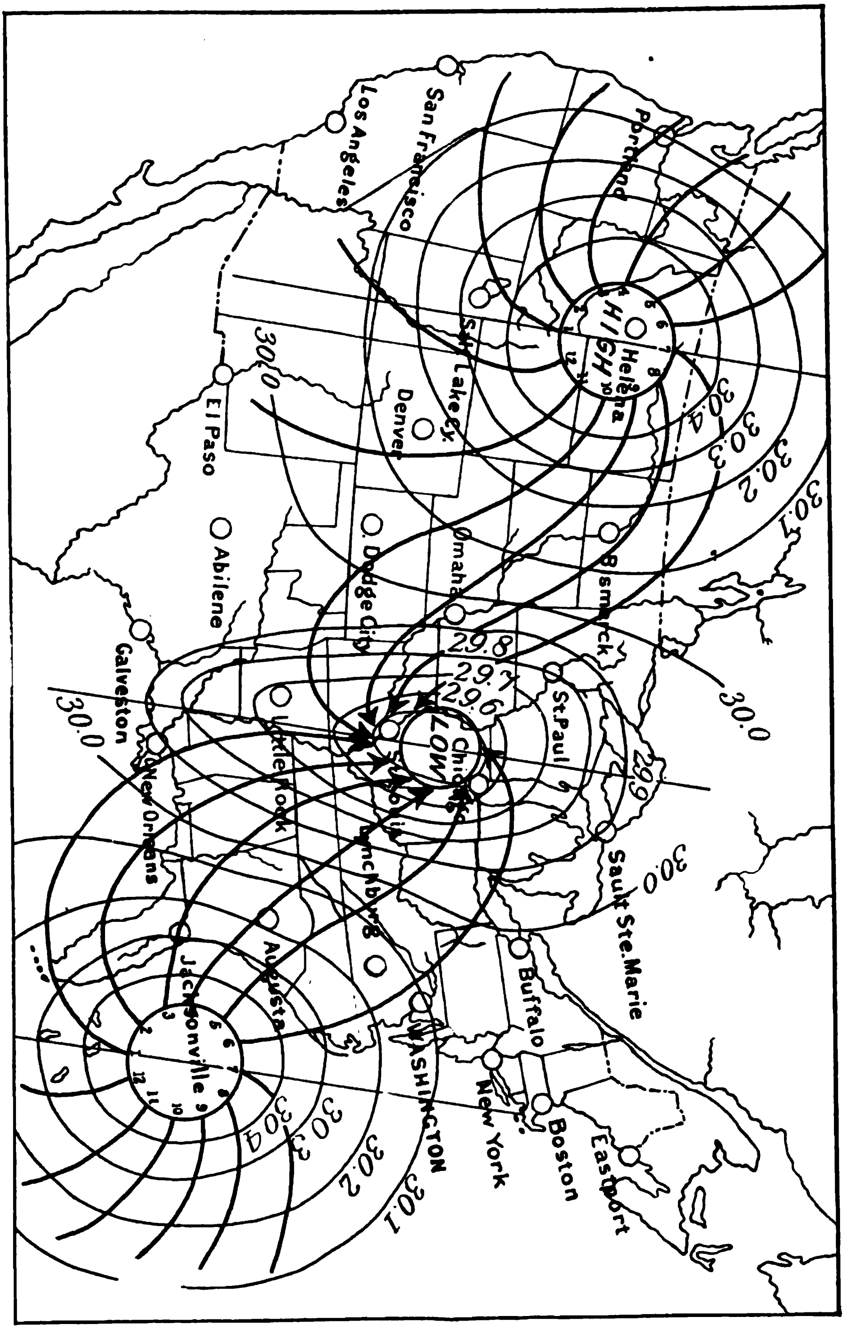

Chart 8.—Isobars and wind lines.

of storms is due to a large extent to the presence of moisture in the air, its condensation, and the liberation of latent heat with precipitation of rain. But in these months we find numberless cases of well-formed storms with deep centers, high gradients, and little or no rain, maintaining this condition for two or three days, and traversing a track of 2,500 miles in length. These facts discredit this theory of the origin of storms and relegate the function of rain to an entirely secondary position.

It may therefore not be unprofitable to examine rather closely the relations of highs and lows to each other, as shown by their isobars and wind lines.

Chart 8 has been very carefully constructed, and represents the average condition as derived from 10 fully developed storms of about this type. It was prepared to form the basis of a strict mathematical computation on the theory of storms and to put to the test some of the assumptions that have been made by writers on the subject. Starting from the center of the highs and also of the lows lying between them, every distance and angle formed by the direction of the wind as it crosses an isobar was measured, and the mean value thus found for 10 cases is incorporated on the chart. The storm is placed central in Illinois, in order to show both the contributing highs on the map of the United States, one of which covers the northern Rocky Mountain plateau and the other the South Atlantic States. This is in general a favorite location, especially for a storm covering the central valleys, and the line joining the centers lies nearly along the middle of the high-pressure belt as it crosses the continent of North America. The other configuration frequently occurring is for the western high to be located as here shown, while the eastern high lies over New England and the Gulf of St. Lawrence, but in this case the upper portion of the isobars would not be shown, as the center would lie so far to the north that they would fall outside the region of our observations.

In order to facilitate the presentation of the facts, the following system was adopted: A line was drawn through the center of the low as nearly along the ends of the oval isobars as possible, and is the axis of reference; parallel to it is also drawn an axial line through the center of the high. Now a circle was placed near the center of the high and divided into 12 parts numbered 1 to 12, the count beginning at the southern end of the axis. Then a line was drawn from the points on the circle thus marked out from the high to the low, following the direction of the wind as shown on the maps, wherever this might lead over the intervening region. The points at which these wind lines, or stream lines of wind velocity, crossed the several isobars were marked, and finally the whole chart adjusted to fit the accurate measurements. It is seen that on the western side of the high the lines 1 to 6 flow into the low, but from the eastern side only the lines 7 to 10; the lines 11 and 12 are probably lost in aimless drifting about, though the air thus unaccounted for must finally be drawn back into the circulation. The form of the wind lines flowing northwesterly is very different from those flowing southeasterly, the former spreading out over twice as wide an area as the latter. Likewise the velocity of the wind is less on one side than on the other—that is, 11 miles per hour in the westerly moving air and 14 miles in the easterly currents, the reckoning including all the lines indicated. The relative distances of the isobars from each other on any line shows the proportional velocity of the wind between them, where the isobars are close the velocity being greater on account of the increasing gradients of pressure. Thus in the chart the wind moves fastest in the region between 30.4 and 30.2, where it flows away from the high, and between 29.8 and 29.5, where it flows into the low. An examination of the angles at which the wind lines cross the isobars shows an important difference, namely, that the average angle is 60° for the winds blowing from the southeast and 48° for the winds coming from the northwest. The spreading out, lower velocity, and greater angle on the east side of the low, with concentrated lines, greater velocity and smaller angle on the west side of it, point to a distinct difference affecting the movements of the air in these two regions. The conclusion is that the winds blow from east to west much less easily than they do from west to east in this latitude and in the United States. Both these qualifications are required, because in this latitude the upper currents of air which are intimately associated with the highs and lows all move rapidly eastward in the upper strata, and hence winds blowing against them meet with resistance; also in the United States the slope of the country is such from the Rocky Mountain plateau to the Mississippi Valley that the wind, as it were, blows down hill and is impelled forward by gravitation. From these causes our northwest winds are violent and steady near the center of the low and the southeast winds are gentle.

The primary function of this circulation is to mix the warm air from the south with the cold air from the north, in order gradually to neutralize the accumulating heat from the sun within the Tropics. These currents are in every sense transporters of the air from one latitude to another, the warm air of the south being carried north and the cold air of the north being driven south. The warm air coming from the Gulf region is charged with aqueous vapor to a high degree, the cold air from the north is relatively dry. It is seen that these two currents in different conditions of saturation and temperature encounter each other along the axis of the low, the effect being there to precipitate the vapor in the air by condensation into water. Furthermore, the air on the eastern side being warm and also being transported to cooler regions in the north, seeks to rise above the ground stratum upward, and this also causes precipitation through expansion and cooling. Thus the rain falls generally to the eastward of the axis of the low and the skies are usually clear to the westward of it.

Writers on meteorology have generally confined their discussion to certain idealized conditions, namely, circular isobars or parallel straight isobars, and based their conclusions upon these assumptions. Occasionally in very violent storms the isobars in the low may become circular, and in hurricanes or tornadoes this is usually the case; in certain parts of the system they may become straight, but this is never the case over a large area. Evidently any treatment of storms that avoids the actual facts as shown in this chart is faulty as an attempt at a complete representation of the natural movements. It is therefore hoped that the publication of this accurate chart will have a tendency to displace those artificial representations given in many text-books.

DECEMBER.

CHARACTERISTICS OF THE WINTER CIRCULATION—DECEMBER STORM TRACKS AND THE PRINCIPAL TYPES OF STORMS.

Beginning with December, and in some years with the middle of November, the very turbulent circulation of the highs and lows in the United States that is characteristic of the winter season is especially to be considered. This greater rapidity of movement and eccentricity of direction is primarily to be referred to the fact that the sun is in the southern hemisphere, so that the temperatures in the polar regions are greatly lowered and the barometric pressures increased. The Tropics are of course at practically the same temperature throughout the year, but in the northern winter the contrast in temperature between the arctic and tropical belts is relatively great, and this gives an increase of power to the thermodynamic engine which the atmosphere of the earth really is at all times. The effort of the two regions of different temperature is to restore the equilibrium that is disturbed by the solar radiation, and this is accomplished by the mechanism of the high and low circulation. There is no portion of the world where this interchange of cold and warm air is so pronounced in latitude as the United States, and this needs a very clear explanation for a full comprehension of the meteorological problem. It will not be proper to attempt to take up this extensive subject in a few sentences, and it will be therefore passed over at this point.

The turbulent winter circulation is chiefly brought into observation by the prominence that the southern circuit attains in comparison with the northern. It will be remembered that the region near the eastern crest of the Rocky Mountains in the neighborhood of Alberta and Montana is fed in by two high-pressure belts, one from the California coast and the other from the northwest British Possessions. From this junction one main path of circulation passes directly eastward over the Lakes and the St. Lawrence Valley to Newfoundland, called the northern circuit, lying directly under the axis of the great eastward upper currents, which are most vigorous in this latitude; the second mean path is along the mountain slope southeastward to Texas, thence eastward over the Gulf States to the Carolinas, and thence northeastward to the Banks of Newfoundland. The two circuits are together like a much-bent bow, with a string uniting the ends. The long southern circuit is a product of three operations: First, the continental cooling of winter, that favors the transportation of highs from north to south before they break up; second, the circulation that builds up the tropical high-pressure belt; third, the rapid eastward drift in subpolar latitudes, that tends to draw every high back into this powerful current. The first carries the cold waves and highs from Manitoba to Texas, the second conserves them in the Gulf States, and the third draws them northward along the Atlantic coast to Newfoundland. Of course it is not easy to separate these three interacting processes very distinctly, but in winter it is not difficult to perceive their operations.

Another principle of great importance in discussing winter circulations is the fact that the so-called high and low pressure belts are somewhat inaccurately described in this manner. From mathematical analysis it is shown that the atmosphere circulates in such a way as to tend to accumulate with high pressure on the outer edges of the Tropics, near latitude 35° north and south, and at the same time to make a subarctic low-pressure belt near the latitude 55°. But, as a matter of fact, continuous high and low pressure belts do not exist. In place of them there is a succession of highs and lows passing over these tracks, the air tending to mass itself in nearly circular areas, alternately cold and warm, from which the observed wind circulation is derived. In the order of natural cause and effect the highs come first and the lows follow, and not in the opposite sequence. Masses of cold air are built up in the high-pressure belt by the effect of general atmospheric motions, the air descending from the upper strata. Between two adjacent highs, and also all around the periphery of a large high, the lows are formed by the action of gravitation, which throws the currents into whirls. These have the effect of forcing the air back again into the upper strata, where it flows off in the general eastward drift. The highs are made up of air descending through at least 5 miles of strata; the lows, on the other hand, are forced up about 2 miles, where they are nearly obliterated by the upper currents. The notion that the highs are fed chiefly by the lows, or that the lows are the primary source of the circulation, has but little foundation, the attempt to make the storm energy do so much work having failed to find the necessary support in modern observations. Having thus sketched the general features of the circulation in the United States for the winter months, we may examine in some detail the facts as given by ten years of the records of the Weather Bureau for the month of December.

The number of storms originating near Alberta and Manitoba for the years 1884 to 1893, inclusive, was 49; entering the United States from the North Pacific coast, 28; forming on the northern Rocky Mountain slope, 10; near Colorado, 14; in Texas, 8; in the Gulf States, 8; to the

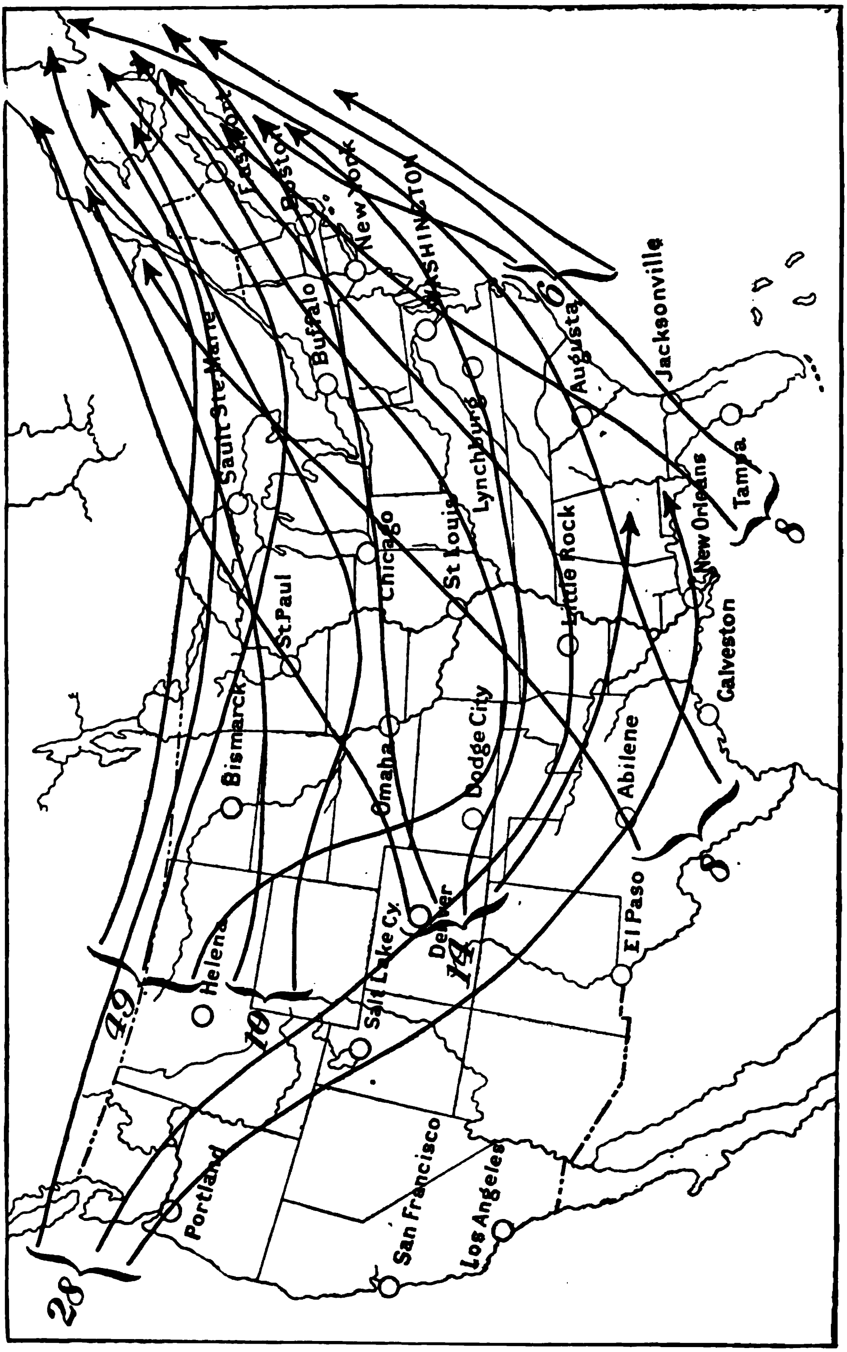

Chart 9.—Storm tracks for December.

east of the Atlantic coast line, 6. Setting aside the North Pacific group, which has a somewhat different history, it may be noticed that the places of formation of the storms just mentioned lie on the great curve that is called the southern circuit. Wherever they form, the track they primarily seek to pursue is one leading directly toward the Gulf of St. Lawrence, where they are caught up in the great eastward current and drawn out over the North Atlantic Ocean. The abnormal tracks are in nearly all cases caused by the rapid march of a high from north to south, while the low clings to its edge, being fed as it gyrates, while it seeks to swing from the south to the north side of the high. When doubt exists in making a forecast, the general principles here enunciated are of great value in deciding what the course of events will probably be. These principles, namely, the interaction of the two primary circuits and the dependence of the lows upon the highs, will probably be found more efficacious in forecasting than the study of types so generally in favor with American meteorologists.

The Alberta type.—When a low forms in the extreme northwest, it is generally found that another low covers the Gulf of St. Lawrence, and that an extensive high area occupies the central valleys and the Gulf States. The center of the high will probably move slowly eastward to the Carolina coast, and thence work northeastward over the ocean. The Alberta low advances in one of two paths: (1) to eastern Dakota in one day, to Lake Superior in two days, to the middle St. Lawrence Valley in three days; or else (2) it will be deflected southeastward to Iowa and Missouri in two days, whence it will make Lake Ontario in one day more. About one-third of the storm centers will be deflected into the southern course, and these are much more erratic in their action and harder to forecast.

The North Pacific type.—These come in over the extreme northern coast, near Vancouver, and separate about equally in numbers into two paths, of which the first is directly eastward over the Lakes and the second far to the southeastward along the mountain slope, generally reaching northern Texas. In this case a high covers the central valleys and the Missouri Valley, the weight of it being near the northern boundary, whereas in the Alberta type it was heaviest in the Gulf States. There will usually be found three lows in sight, one over the North Pacific, one over the Gulf of St. Lawrence, and the third over Florida. It is evident that these are being fed and sustained by the great high, all in the same way and independently of one another, though each is in intimate subordination to the high. The course of the Pacific low will be determined by the movement of this high. If the high passes directly eastward in the northern circuit, the low will follow behind in the northern path; if, on the other hand, the high seeks the southern circuit, the low will maintain about the same relative position, but the tracks will now lie to the southeast over the mountain slope and the Gulf States. It is therefore of primary importance to know, in making a thirty-six-hour forecast, which circuit the high itself will take from the Dakotas. If it goes east, the low will move to North Dakota in one day, to Lake Huron in two, and to the Gulf of St. Lawrence in three days; if the high moves southeastward over the Ohio Valley, the low will be found near Colorado in one day, in the Lower Mississippi Valley in two days, and if it survives, in the St. Lawrence Valley on the third day; some storms of this type have crossed the Gulf States to South Carolina, and have thence moved along the coast line to the northeast. The storms taking the southern track, it is seen, travel with great rapidity, making the long path in the average time of about three days.

The Colorado type.—This is a marked type of storm, forming in the neighborhood of the Colorado mountains. The disposition of the highs is of a very different sort in this case from that of the preceding types. Now one strong high covers the south Atlantic and eastern Gulf States, and a second covers the north Pacific States and the northern Rocky Mountain region. The latter high lies at the junction of the two circuits in the northwest; the former on the axis of the circuit in the southeast; the Colorado low forms in between them, where the counter flow from the highs causes a cyclonic gyration. The northwestern high moves from the California coast southeast to New Mexico, or else farther north to southern Minnesota, in about two days.. The Florida high moves northeast along the coast to New England in the same time. The entire system therefore shifts along the southern circuit. Meanwhile the storm moves in a very regular course northeastward in one day to Illinois, in two days to northern New York, and in three days to the Gulf of St. Lawrence.

The Texas type.—In this case the formation is similar to the Colorado type, the whole system, however, being somewhat advanced along the southern circuit. The eastern high is now central on the Carolina or Virginia coast, and covers the districts east of the Mississippi River; the western high is well to the east and covers the Rocky Mountain slope, being central near Wyoming. Between these a low area is found central in Texas, or near the west Gulf coast. The circulation now carries the Atlantic high northeastward to Newfoundland in two days and the Pacific high to Arkansas in two days. Meanwhile the Texas low moves rapidly northeast over the central valleys to Indiana in one day, to northern New England in two days, while in three days it will disappear from the map.

The Gulf of Mexico type.—The description of this type is about the same as for the two preceding, except that the system is again advanced to the east. These three types show distinctly the same fundamental relation to the southern circuit, being transported farther along from one stage to the other. Finally there are a few sporadic Atlantic coast storms, forming near the Gulf Stream and moving northeastward to the end of the northern circuit, near the Gulf of St. Lawrence. It should be remarked regarding all the lows generated in the southern circuit, especially the Texas and the Gulf of Mexico type, that they make some of the most severe storms that sweep over the Eastern States. The Gulf States still retain much of the heat and moisture peculiar to the summer season, while the highs from the northwest are vigorous with fresh, cold air. This combination is very favorable to the formation of sudden, rapidly advancing storms, with heavy pecipitation, violent winds, great contrast in temperature on the eastern and western sides. The early heavy snowstorms of the Eastern States usually come from these southwesters, and their passage over a district is almost sure to be followed by a destructive cold wave, which, if unseasonable or unusually persistent, causes great damage in the southern portion of the Gulf States. The warnings of the Weather Bureau are particularly valuable in the case of these storms, especially in anticipating violent winds and high temperatures, to be followed by very marked cold waves and freezing in the Southern States.

The central high type.—There is one more formation very characteristic of this season. A large high area sometimes covers the entire country from the Pacific to the Atlantic, giving clear, dry weather for several days in succession. The high holds quite steadily, the isobars being northwest to southeast, or even directly west to east, and it finally drifts off in an irregular manner, and is followed by a low in the extreme northwest.

The system of movements thus enumerated for December prevails quite steadily till March, when it begins to disintegrate in some very irregular and abnormal motions for April and May, introducing the summer circulation which is confined to the northern circuit. Forecasting in the winter deals with rapid movements, great alternations of temperature, and the interplay between the two primary circuits; in the summer it is confined to the northern circuit, while sporadic local storms, tornadoes, and thunderstorms take the place of dominating cyclonic actions.

JANUARY.

IMPORTANCE OF THE NORTHWESTERN DISTRICTS—STORM TRACKS—TEXAS STORMS—COLD WAVES.

Most of the weather conditions described in December continue to operate in January, but with somewhat greater intensity. The turbulent changes in the atmospheric circulation are more pronounced, and the alternations of fair and stormy weather more decided. This is due to the fact that lower temperatures exist over the entire arctic cap of the northern hemisphere, while at the same time the atmosphere within the Tropics is maintained nearly at summer heat, so that a very rapid change in the thermal gradient occurs in going south or north along any meridian. Accompanying this fall in temperature with the latitude, the pressure also is relatively much altered in the summer and the winter distribution, such that in summer a large, nearly permanent low area covers the arctic zone, while in the winter this is divided into two low areas by a comparatively high belt crossing the arctic region. These lows are central, one near Iceland and the other near the Aleutian Islands, while the high belt passes over the British Possessions near the Mackenzie River Valley, northern Alaska, into northern Siberia, whence it goes southwest to unite with the high pressure belt of the temperate zone. The tendency to accumulate masses of cold dry air in the British territory between the Rocky Mountains and the Great Slave Lake region, just east of them, is of special significance in the study of the weather of the United States in the winter. Since the high-pressure belt thus described lies athwart the course of the current of eastward drift that prevails in the upper strata, it is inferred that there is an effort going on to break up the formation of any continuous area of high pressure in the arctic zone, so that these masses of air are intermittently broken off to drift eastward in the northern circuit or southeastward in the southern circuit. Inasmuch as the passage of a large high area is accompanied by a cyclonic circulation, or low, on the front and also on the rear sides, or, in other words, by areas of warmer air on either side, it is seen that this condition tends to produce rapid changes in the temperature of the air that is thus moving eastward over any district.

This northwest region is of especial interest in the meteorology of the United States, for it is practically the heart of the circulation of air that passes eastward, and if it is possible to fully understand the action of the forces operating there it will become much easier to generalize safely concerning many other problems in the physics of the atmosphere. It may therefore be proper to present a few statistics regarding the northwest region. Unfortunately we possess no suitable observations in the exact region where the center of operations is located, between the Great Slave Lake and the mountains, that are continuous over a series of years. It is found, however, that the conditions there generated drift forward to the Dakotas in about one day, on the average, so that, utilizing the observations of the Weather Bureau in those States since 1878, we can form a definite idea of the facts that are involved in the problem. The record of the seventeen years, 1878–1894, gives the following results for the contrast between summer and winter: The mean summer pressure of the Dakotas is 29.90 inches, and the temperature is 67°; the mean winter pressure is 30.14 inches, and the temperature is 10°; winter includes December, January, and February, and summer, June, July, and August, for these conditions. The mean annual pressure is 30.03 inches, and the temperature is 40°, the change being twenty-four hundredths of an inch and 57° F. These are the annual mean values, and of course imply much wider ranges on individual dates.

Now, on examining the changes from day to day in the pressure and temperature, or, as they may be called, the amplitudes of the warm and cold waves passing over the Dakotas, it results that the barometer swings up and down on the average of thirty-five hundredths in winter and nineteen hundredths in summer, while the temperature oscillates on the average about 20° in winter and 8° in summer. These variations are due to the highs and lows passing over those States, and are made up of all the observed changes, large and small, that occur in this connection, some being wide and some very slight. It would be nearly correct to double these figures in order to obtain the wide individual changes that can be noted. It is the passage from the summer values to those of the winter that makes up the seasonal changes, and when these are translated into the winds, gales, hot and cold days, as they come one after the other, it will easily be inferred what a power these small numbers really represent in the action of the earth's atmosphere. In the Tropics, by way of contrast, the amplitude changes are not one-fifth as large for the year. The question naturally arises, What is the exact action or energy in nature that causes this vast accumulation of forces to take place in the region to the northwest of the Dakotas? This is peculiarly interesting from the fact that there is no other region known in the northern or southern hemispheres where so great an output of energy is observed.

The peculiarly rough type of weather prevailing in the United States during the winter as compared with Europe or even Siberia is entirely dependent upon it. There are doubtless a large number of causes at work to bring about this result, yet it is possible to specify some of them, and this will be attempted in connection with the February storms, when this set of influences rises to the maximum power.

The stormy conditions thus generated in the extreme northwest are propagated eastward in a series of irregular, spasmodic discharges, or storm drifts, that cover the United States, the intensity diminishing gradually as the storm power becomes exhausted on the way to the Atlantic coast. The belt of the Northern States lying under the great eastward drift current is swept by these violent changes nearly all the winter; not infrequently these are projected so far south as to reach the Gulf States with gales and cold waves. The storms forming in the Southwestern States, near Texas, are in reality the effect of the work done to the northward in Manitoba, the activity of a single storm covering many thousand miles when the interchanging winds of the highs and lows are considered.

Conspicuous features of the distribution of the origin and the tracks of storms, when the months of the year are compared with one another, are the facts that as the winter approaches the number of storms forming in the Southwestern States increases decidedly, and that the tracks loop southward over the Rocky Mountain slopes. In the months May to December the average number of Texas storms is 6, but in the months January to April it is 17, for each month, as a total for the ten

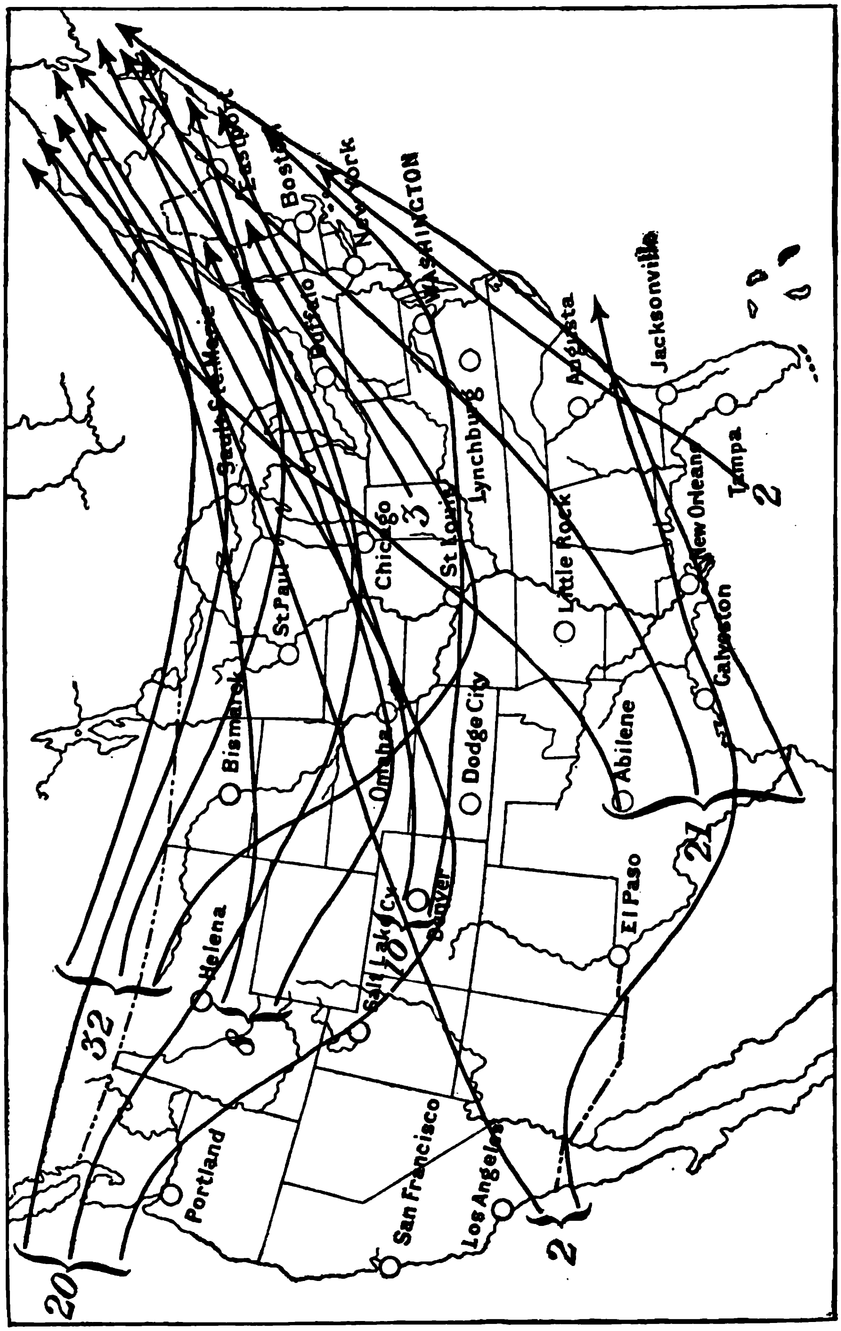

Chart 10.—Storm tracks for January.

years 1884–1893. The effect of this is to cause many more storms to cross the south central valleys, the Gulf, and the South Atlantic States; also the storms beginning in the northwest are often forced southeastward to the Gulf States before they recurve to the Gulf of St. Lawrence. These effects are apparently due to the great highs forming to the north of Montana, which are driven forward to the south and propel the storm in front of them in the tracks just indicated.

An examination of the types peculiar to the several districts gives rise to the following data for January: In the ten years discussed there were 98 storms, 32 belonging to the Alberta type, 20 to the north Pacific coast type, 8 to the north Rocky Mountain plateau type, 10 to the Colorado type, and 21 to the Texas type; 2 others formed on the south Pacific coast, 2 in the eastern Gulf, and 3 near the Ohio Valley.

An examination of the international charts regarding the causes producing storms in the Saskatchewan Valley shows that they are usually preceded by a loop from the Alaska low intruding upon this region, which is then broken off by the action of the highs in the neighborhood. It is seldom that any distinct gyratory movement of the wind is seen around an advancing center, until the loop is in the valley east of the mountains, as far north as 50° to 55° latitude. If the same cause operates more to the south, in latitude 45° to 50°, then a true cyclonic low is formed over the ocean and advances upon the coast as one of the North Pacific type. These two types, forming under the same general conditions, embrace more than one-half of all the January storms. Two-thirds of these reach the Atlantic coast north of the fortieth parallel, and if they move in the northern circuit over the Lake region the succession of warm and cold, stormy and fair days will be very regular. If they are, on the other hand, deflected southward, the probable course of the track is harder to determine, the rate of advance and the severity of the storm will be more difficult elements to include in the forecast. The average velocity of eastward movement is 37 miles per hour. About two-thirds of the storms of the Alberta type move eastward over the Lakes, but one-third are deflected as far southward as Missouri, that being the average place of turning northeastward.

In a similar way about one-third of the North Pacific coast storms bend southeastward to nearly the same latitude, 37°, but they recurve farther to the west in the States of Colorado or Kansas. The tracks of this type are much more spread out after crossing the mountains, but they generally make the lower Lake region and advance down the St. Lawrence Valley. An important feature regarding the precipitation of the storms moving in the northern circuit is that before the center reaches the Upper Mississippi Valley the fall is on the western or following side of it in Montana, the Dakotas, and Minnesota; but within a few hours the precipitation is transferred to the eastern side of the center into the Lake region, and then advances before it over the

Middle States and New England. It is hard to include such facts in the theory that rain or snowfall is essential to the formation of storms or that lows advance to the region of greatest precipitation. The order of events seems rather to be that the lows are products of the highs, and the precipitation effects of the lows.

In point of number and in severity of the winter storms the Texas type stands in the front rank, and deserve particular attention from the forecaster. Some of them form in northern Texas, near the terminal slopes of the mountains, and they usually advance to lower Michigan and reach the Atlantic Ocean in about forty-eight hours. Others originate in southern Texas, and these are likely to move more to the eastward over Tennessee and Kentucky, along the Appalachian range, the march from Texas to New England taking about two days. Still others form in the western Gulf or near the Rio Grande River, and these are usually found to skirt the Gulf and the Atlantic coasts and to reach the New England coast in forty-eight hours. In general, immense areas of rainfall accompany these storms, covering the Lower Mississippi Valley and the Ohio Valley in twenty-four hours, the Atlantic and New England States in the next twenty-four hours. The rise of temperature in the front is excessive, and the passage of the storm is likely to be followed by a severe drop in the temperature, with a cold wave in the Southern States and clear, dry weather.

The northern and southern types now mentioned comprise three-fourths of the January storms, the others being sporadic or else abnormal, and depending upon the relative location of the high areas and their movements. One of the South Pacific storms moved northeastward to the Lake region and the other directly eastward to the South Carolina coast; the 2 east Gulf storms followed the Atlantic coast line to the north; the 3 Ohio Valley storms moved to New England. The northern Rocky Mountain (8) and the Colorado (10) storms all moved with great regularity to the northeast, except that the former generally looped southward into Nebraska.

The cold waves of the winter season, setting in during the second half of November and continuing until April, are important matters for the attention of the Weather Bureau.

For forecast purposes in connection with cold waves, the country east of the Rocky Mountains is divided into five districts, according to the relative frequency and intensity of the waves; the region most marked in these respects embracing the Northwestern States, and that least marked including Florida and the Gulf coast.

The temperature falls required to constitute a cold wave vary with the districts and the seasons of the year, but range from 24-hour falls of from 20° to 16° with minimum temperatures of from 16° to 32° during the months of December, January, and February, to the same 24-hour falls with minimum temperatures of from 20° to 36° during the remaining portions of the year. In verifying a signal ordered to forecast a cold wave these conditions must be fulfilled.

Cold waves come with the quick advance of a high area from the north, and they are materially strengthened by the passage of a vigorous storm center northeastward along the edge of the high, the latter tending to raise the temperature in the front and the former to depress it decidedly in the rear. It is often a very difficult matter to mark out successfully the exact boundary of this extreme fall of temperature because the rapid changes in the relative places of the highs and lows can not always be definitely foreseen. In spite of this the Bureau is able to give such timely warnings of sudden drops of temperature as to be of great value to the transportation and commercial interests of the United States.

FEBRUARY.

IRREGULAR RATE OF EASTWARD DRIFT OF STORMS.

Under the month of January an attempt has been made to direct attention to the importance of the northwest region in the meteorology of the United States. On the eastern slope of the Rocky Mountains, in the Canadian possessions, in the neighborhood of 115° west longitude and 55° north latitude, there exists a peculiar mechanism whose work is to turn out a series of highs and lows, following each other in an apparently fortuitous sequence, which then advance over the United States in the tracks that have been described.

The leading feature in the meteorology of the earth is the fact that the sun's radiation warms the tropical and temperate zones, leaving the arctic regions cold. From this unequal temperature there are produced convectional currents, of which the primary are the tropical trades blowing westerly and the upper current in the temperate zones blowing easterly. The movements of our highs and lows have much to do with this eastward current, and upon it depends the main eastward drift that is at the basis of the practical forecasts of the Weather Bureau. The most remarkable feature regarding this eastward drift, over the entire hemisphere, is that sometimes it is very rapid and at other times very slow, the acceleration and the stagnation succeeding each other at uncertain intervals.

This irregularity is, on the whole, the most difficult feature in forecasting to take account of, and on account of it occur many of the failures. A sudden slowing up of the drift will necessarily throw the whole forecast into confusion, and an unexpected rush will also produce disaster. This peculiar change in rate of motion seems to occur simultaneously over the two continents and the two oceans, and is therefore probably due to the work of some great cosmical agency, a discussion of which will be found later in this paper.

The tracks for February are similar to those for January and March, and much of the analysis of storms is equally applicable to these three months. The intensity of the weather conditions gradually rises from

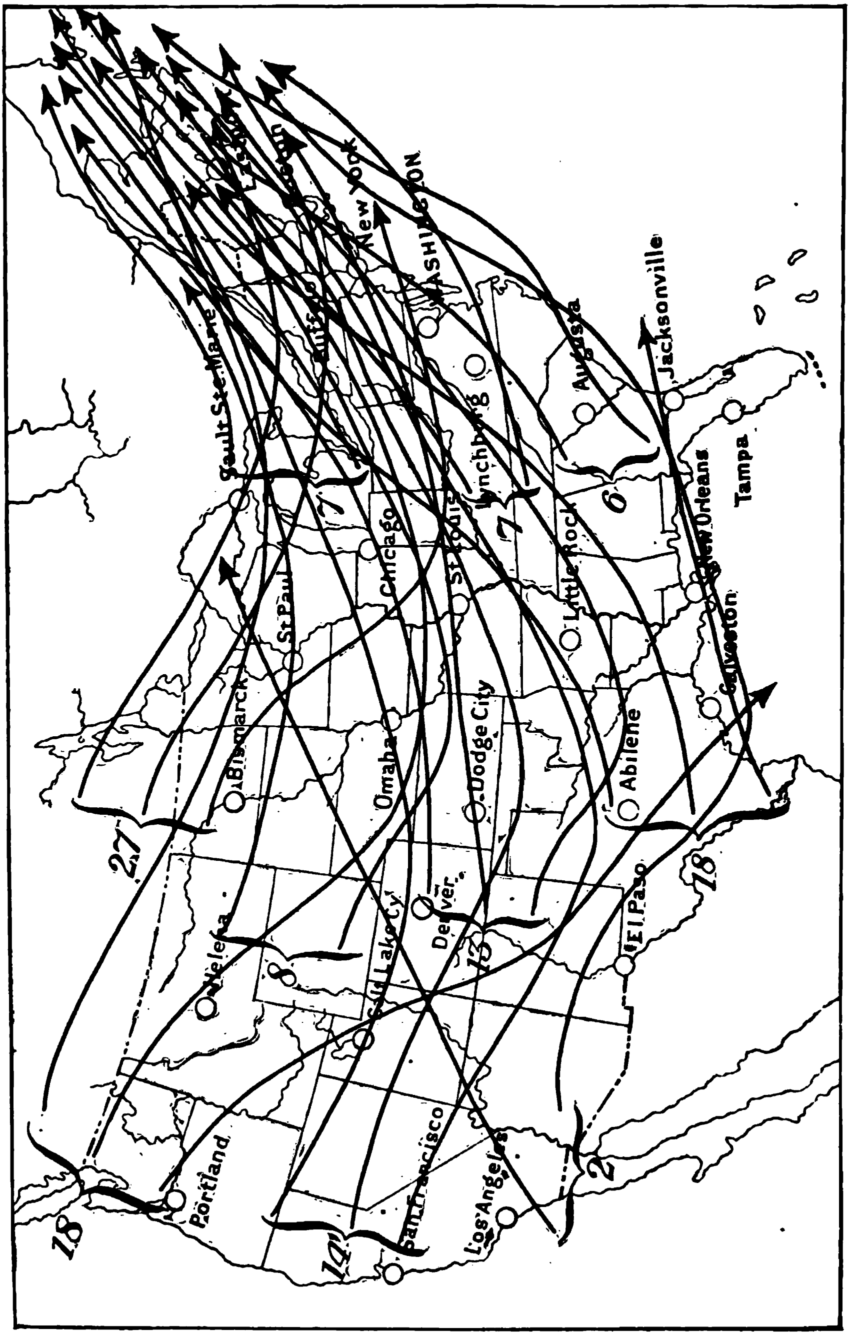

Chart 11.—Storm tracks for February.

September till it culminates in February, and thence falls off till June, when the summer relations become reestablished. A count of the number of storms in February for ten years 1884–1893 shows that 27 originated near Alberta, 18 on the North Pacific coast, 8 on the northern Rocky Mountain plateau, 13 in Colorado, 18 in Texas, 6 in the east Gulf and South Atlantic States, 7 in the central valleys, and 2 on the South Pacific coast, making a total of 99, and averaging 10 each month.

Approximately 20 per cent of our February storms come from the Pacific Ocean and States, 24 per cent from the Gulf of Mexico and Gulf States, and 56 per cent are developed in the interior. The tracks converge, as usual, to the Gulf of St. Lawrence, when the movement is normal. The anomalous tracks usually have a decided loop southward along the Rocky Mountain slope, whence they may advance and be lost near the Gulf of Mexico or recurve to the Lake region and the St. Lawrence Valley. These storms almost always move in front of a large high area, whose rapid and vigorous movement thrusts the northern storm to the southward before they can gyrate to the east front along the periphery of the high.

The Texas storms, as in other months, are rapid marchers, and are attended by widely extended rain or snow precipitation. If there is no high over the Gulf of St. Lawrence which retards the northeastward movement, they reach New England in forty-eight hours; if a high hangs persistently in that region, they may require ninety-six hours. If a high is located in the northwest, threatening a cold wave, this will reach the Gulf States if the movement is rapid; it will be dissipated in rain or snow if the low is much retarded. Special attention should be directed to the probable behavior of the St. Lawrence high, as upon this will depend success in forecasting the advance of a large storm from the southwest.

MARCH.

THE BREAKING UP OF THE WINTER CONDITIONS AND THE WIDELY SCATTERED SYSTEMS OF STORM TRACKS.

March impresses itself upon the dweller in the northern half of the United States as a particularly windy and disagreeable month, with strong alternations of wintry and mild weather. This is due to the breaking up of the conditions that have prevailed since December, and the processes of return to spring and summer. There is in the Arctic zone an enormous amount of cold material to be disposed of, covering the northern regions in the form of ice and snow; at the same time the southern zone is becoming decidedly warmer in consequence of the advance of the sun to the northern side of the equator.

The United States is peculiarly the theater of this contest between the giants of cold and heat, and they stagger back and forth over this territory as one or the other is for the time being in the strongest form. The cold waves launch themselves from the North and carry

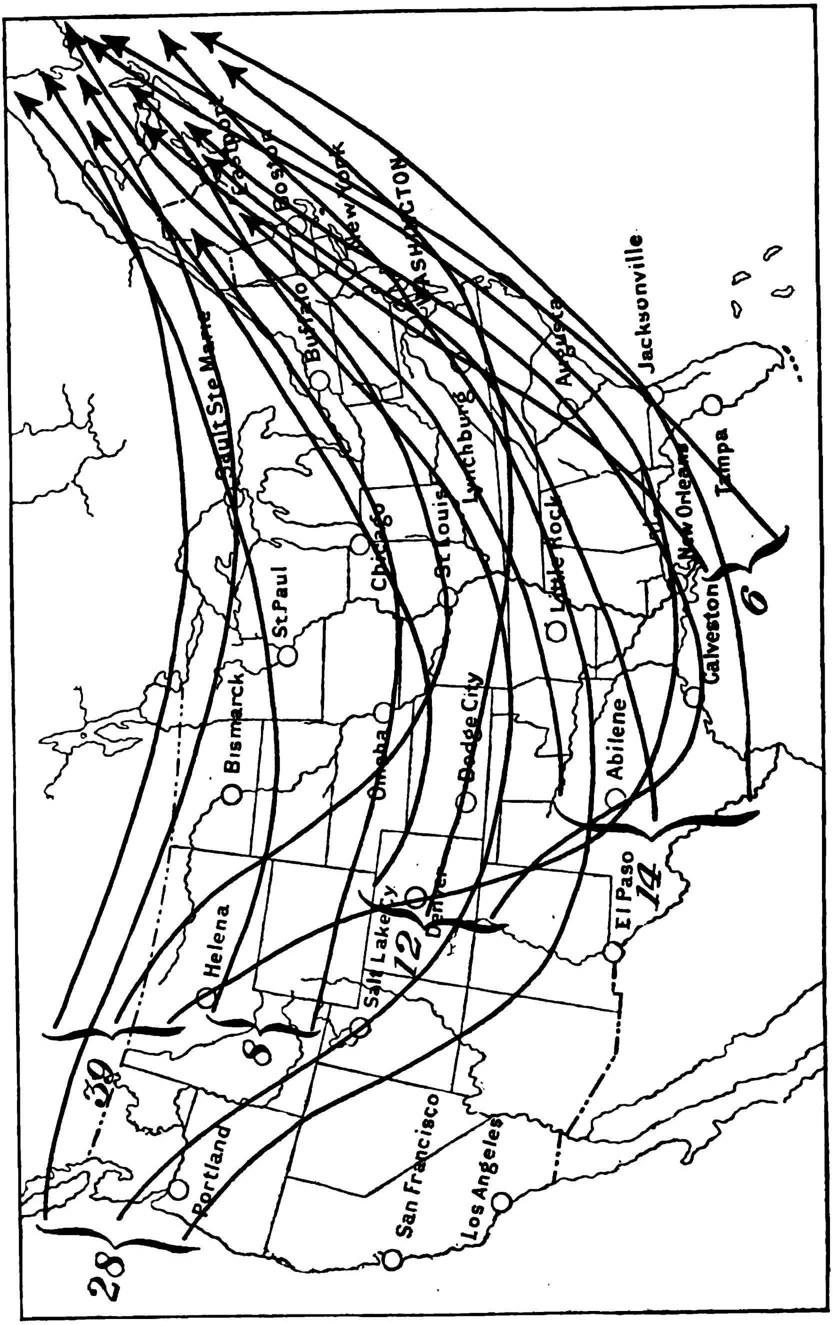

Chart 12.—Storm tracks for March.

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their icy chill to the warm Southern States; or, on the other hand, the warm currents of air from the South advance far into the North, and this alternation causes a rapid variation in the temperature and the other weather conditions at stations of the middle latitudes.

An examination of the storm tracks for March gives very definite evidence of the effect of this struggle for supremacy. Instead of being confined to the neighborhood of the mean tracks, it is found that they spread out over the entire territory of the United States from north to south. The phenomenon of looping southward along the Rocky Mountain slope before recurving northeastward to the Gulf of St. Lawrence is most pronounced.

The storms which first develop in Alberta or on the North Pacific coast may advance directly eastward over the Lakes to the Gulf; or they may be pushed south and recurve in Colorado, Missouri, southern Illinois, or southern Indiana, in order to move to the St. Lawrence Valley; or else they may be propelled still farther south along the Rocky Mountain slope to Texas and the Gulf coast, whence they proceed to the South Atlantic coast, and then turn northward to Newfoundland. Not a few of these storms dissipate in the Lake region or the Ohio Valley; others will persist in a path of nearly 5,000 miles, from Alberta to southern Texas, South Carolina, and finally to Newfoundland.

It may be asked, What is the primary cause of these very widely scattered storm tracks in March, as compared, for example, with the regular distribution of those noted in October? The answer is clear and comprehensive. It is that the lows, or storm centers, are in all cases developed along the edge of the high area, and that they depend on the high for the source of the great volume of air that circulates through them, and to which the motion peculiar to the configuration of the low is due. As the high moves, so also moves the low, partaking of its eccentricities as to direction, rate of motion, and distance of propagation. If a high forms on the great plains of the British Possessions under the magnetic auroral belt, just eastward of the mountains, a low will also at the same time develop to the south of it, in Alberta or Manitoba. As the high is driven southward it may work into the central valleys, holding the low still to the south, by which time it will mark out a track southeastward to the Gulf States; then the low will gyrate along the front and eastward side of the high, which may halt or dissipate in the South Atlantic States, while the low, still drawing its supply of air from the high itself, advances northward and is taken up by the great eastward current of latitude 45° to 50°. The unequal distribution of the tracks of the storms in March is therefore due to the irregular propulsion of cold masses of air from the Arctic regions into the middle of the North American continent.

A peculiarity of continental action is that in summer the interior is warmer than the borders, but in winter the interior is colder than the coasts. The upper Lake region and the Upper Mississippi Valley are especially remarkable for this feature. Between meridians 95° and 100° and between parallels 50° to 55° the change in temperature is the greatest known in North America. It is coldest in winter there, and also it may become the hottest part of the country in summer; the range of temperature may be from 45° below zero in winter to 105° above zero in summer, a change of 150°. The encroachments of spring upon the winter in North America proceed from the extreme southwest, the Gulf of California, and the Colorado River Valley, and advance toward the northeast. There is constantly going on a vigorous interplay between the cold pole in the Red River Valley of the North and the heat that is working in from the lower Rocky Mountain plateau and the extreme southwest.

This leads to a description of one of the most characteristic features of the advance of the summer upon the North American continent. In winter the lines of equal normal temperature, that is, the isotherms, are grouped about the cold pole in quite a symmetrical manner, bending southward in the interior as they pass from the Atlantic to the Pacific coast. This configuration may be regarded as normal from November to March, inclusive.

In summer the formation is somewhat inverted, the lines bending northward from the coasts toward the interior, though the crest is now farther west, in the dry Rocky Mountain region. The Gulf of California is the central region of heat, and the crest extends from Yuma, Ariz., northeastward toward the Dakotas. This inversion of the crests of the isotherms in the interior of the continent is necessarily accompanied by a notable change in the configuration of the areas of equal pressure.

When the winter cold is established the high-pressure belt is very firm in the Rocky Mountain districts, and is shown by a persistent high area in that region, which may linger many days, with apparently no active effect upon the weather conditions in the central valleys, and it is therefore called a "dead high." This western high is often a well-established feature from November to March. During September and October conditions favorable to the development of this high are improving, and during April and May their destruction is taking place.

In the summer this permanent high is replaced by a trough of low pressure, extending from the Gulf of California, where it is always lowest, along the plateau region to the Dakotas. At that time a more or less permanent high is located on the northern Pacific coast, and another is central in the east Gulf States. The cause of the formation of these different types of highs, as modified by continental action, is one of the most important problems presented to meteorology for solution, but, unfortunately, our knowledge of the physics of the subject is very imperfect.

The transition of the winter high of the Rocky Mountains to the summer low is indicated by a peculiar change that should be considered. The first sign of the coming modification is that the high area is flatter, covers a wider territory, especially on the northern plateau and slope, and is less likely to build a marked center in the neighborhood of Utah and Wyoming. The second symptom of the change is that the center of the high slides gradually to the northeastward, passing over the Dakotas to the upper Lake region. Another way of stating the same fact, as shown by the normal charts extending over twenty years, is that the axis of the polar high pressure, which is tributary in the winter to the mid-latitude high-pressure belt, gradually works eastward from near the base of the mountains in western Canada to the shore of Hudson Bay, and bends so far southeastward as to discharge to the east of the Lakes instead of to the west of them in the Upper Mississippi Valley. This change produces a very different aspect on the map for the purpose of forecasting. When the discharge from north to south is along the Rocky Mountain slope, the formation of storm centers, and the axis of cold waves is usually in the Missouri and the Upper Mississippi valleys; but when the output from the Arctic zone is to the eastward of the Lakes, then the western region is comparatively flat and quiet, but the cold waves and the high area from the north are projected into the Lake region and New England. These often come very suddenly, and almost without preliminary indications on the charts, being usually accompanied by a low center in the Gulf of St. Lawrence, upon whose western quadrants the high advances rapidly. There are several weeks, especially in March, when an uncertainty exists regarding the axis of the Arctic high, whether it be to the west or the east of the Lakes, and this causes great confusion in the tracks when collected for a number of years on the charts. In April and May the high has moved so far eastward, nearly to Hudson Bay, as to make the majority of the movements from the north occur to the eastward of the Lakes. In the meantime the low trough has advanced so far from the extreme southwest as to make itself the dominant feature of the Rocky Mountain districts; hence the forecasts of cold masses of air for the Middle States and New England become the leading feature for consideration, and in fact the attention of the forecaster is necessarily fixed upon this region.

A count of the number of storms originating in the several districts shows that Alberta is to be credited with 39, the North Pacific coast with 28, the northern Rocky Mountain plateau with 8, Colorado with 12, Texas with 14, and the east Gulf States with 6, making a total of 107 for the years 1884 to 1893, inclusive. The Alberta storms move in part along the northern circuit, some loop down the mountain slope to Colorado, and others reach Texas before recurving to the northeast. The North Pacific storms show an even greater tendency to loop southward to the west Gulf States, though some move directly eastward, and others take a middle course between these extremes, the result being to cover the western region with the tracks. The Colorado storms are also inclined to loop southward, and the majority of them cross the Gulf States to the Atlantic coast before moving northeastward, although a few may pass over Lake Michigan and the lowe lakes. The Texas storms almost invariably move eastward at first, a part of them taking the interior track westward of the Alleghany Mountains, the remainder following the coast line from North Carolina to Newfoundland. The storms that originate in the middle Gulf States generally touch the middle Atlantic coast near Virginia or North Carolina, whence they pass northward over New England. As in other months when the Gulf of Mexico or Texas storms are attended by heavy precipitation, they are likely to produce widespread and even disastrous effects in the shipping ports along the Atlantic coast. It takes about forty-eight hours for such storms to reach New England, unless decidedly retarded by a persistent high in the St. Lawrence Valley.

It may be observed that the magnetic auroral belt runs directly along the region from which the high advances, whether the discharge be from the western or the eastern side of the Lake region.

The magnetic force seems to be efficient in producing meteorological effects in proportion as it can operate in cold atmospheric conditions. Hence the encroachment of warm air from the southern Rocky Mountain districts as spring comes on is unfavorable for this kind of action, and it seeks to transfer its seat to the portions of the interior of the continent that still retain low temperatures, namely, to the Hudson Bay districts; finally, as the summer heat conquers this cold territory, the winter high passes away entirely, and the whole arctic region is covered by low pressures, extending from the north Atlantic to the north Pacific Ocean and passing directly across the Arctic Ocean.

The unsettled weather of the month of March, especially in the northeastern portions of the United States, with its rapid alternations of warm and cold winds, often reaching considerable violence, is therefore the parting salute of the cold winter that has prevailed for five months throughout the northern cap. A most impressive feature of this change, as deduced from a close study of the barometers and temperature readings of the Weather Bureau, is the suddenness with which the struggle is concluded in the northwest, for March often comes in with a very violent action, and this is almost certain to end about the 20th of the month with moderate movements of the air. The struggle is prolonged in the east, but is usually about over by the 10th of April.

APRIL.

FORMATION OF THE ROCKY MOUNTAIN LOW—CAUSES OF RAINFALL—STORM TRACKS—FROSTS IN SPRING.

The weather conditions prevailing in April indicate a transitional state between the winter and summer seasons, with the winter types on the whole the more vigorous still. The contrast between March and

April may therefore be mentioned in order to explain the modification in the weather now setting in. The most prominent feature, on the whole, is the drifting of the Rocky Mountain high pressure to the northeastward, nearly into the Lake region, and the supplying its place by the more permanent low which enters that region from the southwest, intruding northward from the Gulf of California. The result of this change is to transfer the discharge of the cold air from the interior of the continent, where it still lingers near Hudson Bay, from the western to the eastern side of the Lakes. Hence sudden outflows of cold winds occasionally advance over the Middle States and New England, by which one is reminded that winter has not yet gone from those districts. Usually there are few well-defined symptoms of these invisible highs beyond the existence of two lows, one near New England and the other to the west of the Lakes. In such cases it is generally the effect of a cold area of high pressure developing to the northward of the limits of the territory represented by the weather map, and colder weather may be forecasted from the lower lakes to the Middle Atlantic and New England coasts.

In contrast with these cold northwest winds of the east, it is found that strong warm winds prevail in the southern and Rocky Mountain districts. They are often of great velocity and carry immense quantities of sand and dust over the plains to the northward. These may be called "southers," in distinction from "northers" of winter, which prevail in Texas and Arkansas, being the flow of very cold air southward along the mountain slope as a high advances to the southeast. An attendant feature of the south wind is to carry the isotherms rapidly to the northeast, from Texas to the Lakes, causing hot weather in the Mississippi and Missouri valleys, often in unseasonable severity. This process may go so far as to make conditions for severe local storms, thunderstorms, and tornadoes in Missouri, Iowa, Illinois, and would no doubt do so more frequently if the air were sufficiently charged with moisture, which does not always happen at this time in the spring.

At any rate, such a marked interchange of cold and warm winds in the central valleys is an important part of the April weather, and it is attended by rapid and wide oscillations of the barometer in these regions. There frequently occur great depressions of the barometer over the entire mountain plateau and slope, sometimes with high wind velocities, sometimes without them, even though steep gradients exist, in which there may be but little precipitation. This is probably due to the fact that in the increase of the general heat of the atmosphere in the middle latitudes the capacity of the air for greater quantities of moisture is increased, while there is also a corresponding diminution in the size of the cold masses that may be projected into the warm masses in order to produce a fall of rain. Hence, strong gradients and wind do not necessarily imply much rain, and such storms may move to the Atlantic coast and go over, as it were, very dry, with only an occasional shower. The showers of April may be simply understood: Instead of the atmosphere being collected into great sheets of cold and warm air, which, as in winter, move eastward over the United States in a succession of waves, the cold and the warm masses become broken up into smaller portions or patches, which lie interspersed among each other in an irregular way. The contact of such masses of air in smaller bodies tends to cause local showers, and this condition lasts for a month or two, till the entire northern cap becomes warmed up, when summer conditions become fully established.

It may be not uninteresting to note the three ways that exist in the atmosphere of condensing moisture suspended in the form of aqueous vapor into rain. The first is the adiabatic cooling, which consists in the cooling of the air by expansion when it rises from the lower to the higher strata, by which the cumulo-nimbus and nimbus clouds of summer are chiefly produced, from whose bases the rain falls. The second is the intimate mixture of two masses of air having different quantities of vapor in them, but it has been shown that only small amounts of rain can in this way be produced, although very extensive fogs may be formed. The third is by far the most important, and, although in some respects a complex process, it may be called direct cooling by contact. One of the most important physical properties of air at different temperatures is a reluctance to mingle. Such masses will rather flow alongside each other in distinct strata, like oil and water, with contact on the surface. The effect of this is seen in many of the cloud forms that spread over the sky, showing exactly where the currents of different temperature touch each other. In the cyclonic circulation of the atmosphere, which is to be referred primarily to the counterflow of currents from two adjacent high areas, there is a powerful force that produces a breaking up of the currents into shreds of air, warm and cold in quick alternation, in the interflow especially in the southeastern quadrants of the lows. Here the direct contact in the air of masses having moisture in suspension with the cold masses that are partially dry tends to form rapid condensation and hence rainfall. The operation of such a principle extending to the minute portions of the air will cause the fall of the moisture as rain, and thus dry the air thoroughly. Since the low is sustained between two highs and drifts eastward with them, this process of direct cooling between minute masses of air is going on continuously in the eastern quadrants of a storm where the rain falls, and the passage of the low is followed by clearing and cool weather in the current from the northwest that has not yet been able to reach any moisture-laden air. No doubt all these three processes are at work more or less simultaneously, but it is clear that direct cooling is the most efficient of all in producing ordinary rainfall in middle latitudes.

An examination of the storms and tracks for the years 1884–1893 shows that 24 originated in the Alberta district, 23 on the North Pacific

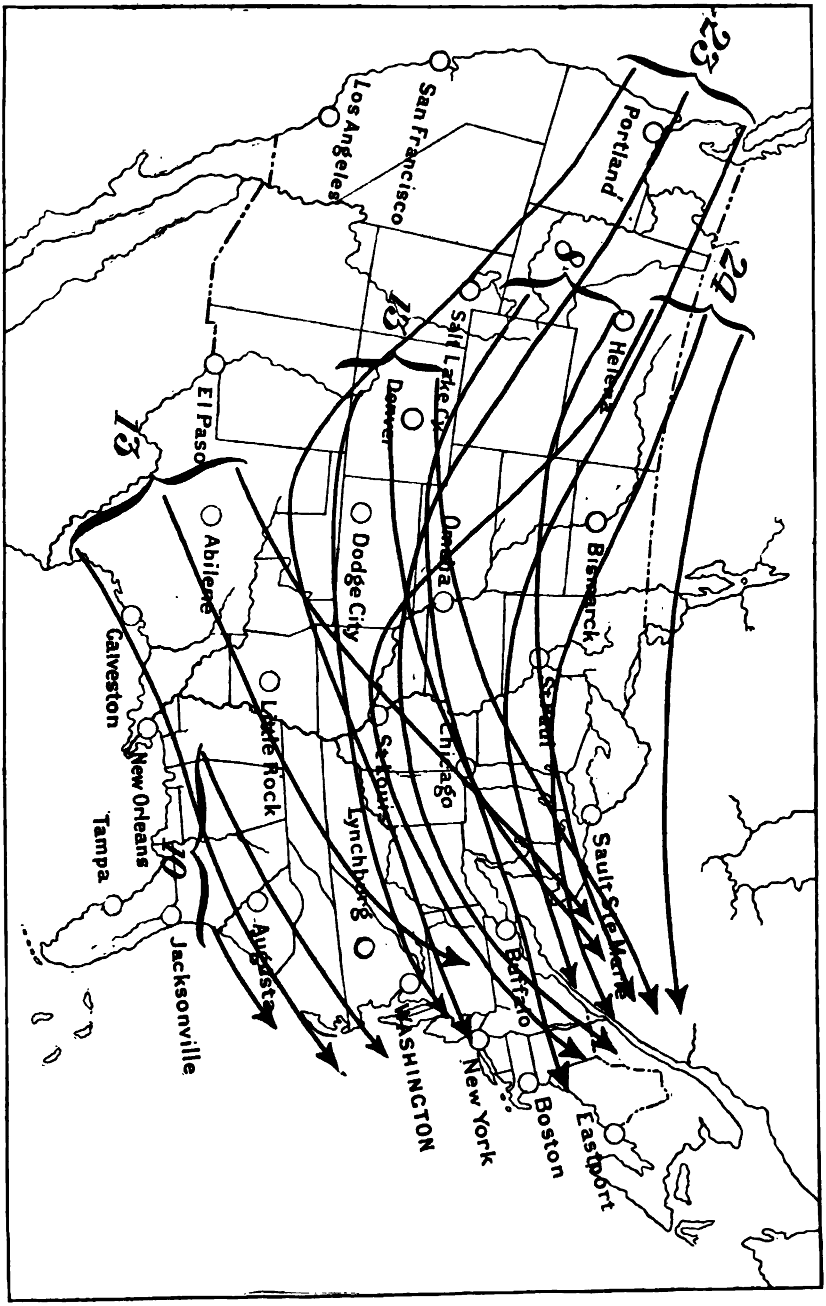

Chart 13.—Storm tracks for April.

coast, 8 on the northern Rocky Mountain plateau, 13 in Colorado, 13 in Texas, 10 in the east Gulf or south Atlantic States, a total of 91, 9 per year, or 1 every three and one-third days. The Alberta type shows a decided eastward movement in the northern circuit, with a moderate looping in the case of a few storms into the Ohio Valley, before reaching the Gulf of St. Lawrence. A high area usually occupies the central valleys when this type of storm forms, and as the high drifts northeastward the low follows behind it. The movement is somewhat slower than in March, and by the end of the month at least one day more is required to make the eastward march. The North Pacific coast type is characterized by a decided southern looping over the mountain slope to Kansas or Missouri before recurving to the northeastward over the Ohio Valley and Lake region. In this case a very large high covers the mountain slope and the central valleys, and there is a possibility of the high moving in either one of two paths, which is quite different from the case of the Alberta type. Either the high may move directly northeast to the Gulf of St. Lawrence or else it may move southeastward to the Florida peninsula. In the former case the eastward drift of the upper strata of air seems to be more influential, and in the latter it is the tendency of the air to settle in the high-pressure belt of the Tropics over the South Atlantic coast that appears to have dominated. In the first instance the low may move much more directly eastward from the Pacific coast, and in the second it advances far southward and then recurves along the northern border of the high as it continues to discharge through the low. This type of low in April takes about five days to reach the Gulf of St. Lawrence; in case the storm moves to the Lower Mississippi Valley, it may dissipate near the Gulf of Mexico on about the fourth day. The Colorado type shows little tendency to settle farther southward, but these storms advance directly northeast in rather a wide track, either to the middle Atlantic coast or to the lower Lake region, over the Ohio Valley. In this case, also, the high shows the same uncertain impulse to move either northward or southward along the Atlantic coast, as in the Pacific coast type. These storms also move slowly, and in many instances they take five days to reach the Gulf of St. Lawrence. A few of them likewise dissipate near the mouth of the Mississippi River.

The Texas type may perhaps be subdivided into two groups of storms, those originating in western Texas and moving northeastward on the inside track west of the Alleghany Mountains, and those which form near the west Gulf coast and move eastward to the coast on the outside track east of the mountains or along the coast line. These storms generally form with a high in the Lake region, or to the northeastward, and they usually advance rapidly to the Gulf of St. Lawrence, reaching that region in about three days. The South Atlantic type occurs with a high on the Rocky Mountain slope, heaviest in the southwestern districts, and the storm advances rapidly along the coast line to the north. It also happens sometimes that another low of the Alberta type is advancing eastward, and the conditions are then favorable for diverting this low from the St. Lawrence Valley track southward over the Middle States to New England. Thus these two independent storms may unite in the neighborhood of New York City, and in that event severe winds and rain may develop on the North Atlantic coast. Sometimes such a storm instead of moving off to sea holds nearly the same position for several days, with a cold northeast wind and rain that causes very disagreeable weather in the New England States. In all cases the variation of rapidity of the eastward movement is the chief source of the perplexity in forecasting. It may be laid down as a rule that no inference can be drawn from the previous cases regarding the storm under consideration. It must be treated on its own merits, from a knowledge of the total conditions then existing.

One of the important duties of the Weather Bureau is to furnish warnings of frost and other conditions injurious to growing crops, and as the frost line moves south in the autumn and north in the spring over the United States, great care has to be exercised with these warnings, in the autumn for harvesting and in the spring for protecting the young plants. Therefore, the following districts are attended to in the course of the year: The tropical fruit districts, the sugar and sorghum districts, the cotton region, the rice districts, the vegetable and fruit districts, the stock-raising districts, the cranberry districts, and the tobacco districts. For cranberries the forecasts are made from May 1 to November 1; for sugar, from October 1 to April 1; for tobacco, from September 1 to November 1; for fruit and vegetables, from September 1 to June 1; for cotton, until the cotton is gathered or freezing weather occurs. The time for which the frost warning is sent to the different States is approximately as follows: All the year to east Florida, west Florida, southern Mississippi, southern Louisiana, and southern Texas; after February 15 the frost warning line is through the central part of South Carolina, Alabama, Mississippi, Texas, and all of Louisiana; after March 1 it includes North Carolina, Kentucky, Tennessee, southern Indiana, southern Illinois, Missouri, and Arkansas; after April 1 it is as far north as New York, lower Michigan, Wisconsin, Minnesota, and South Dakota. In the autumn the line advances southward in almost similar proportions. Frosts and freezing weather can usually be predicted twenty-four hours in advance, and in spite of the fact that failures sometimes happen, generally in the nonoccurrence of frosts expected, there is no doubt that all farmers who follow the warnings of the Weather Bureau carefully and protect their plants will save more than their neighbors who do not use the forecasts.

MAY.

STORM TRACKS.

A description of the weather conditions for May must necessarily resemble closely that already given for April. The transition from winter to summer is, however, much advanced, and the frost line disappears

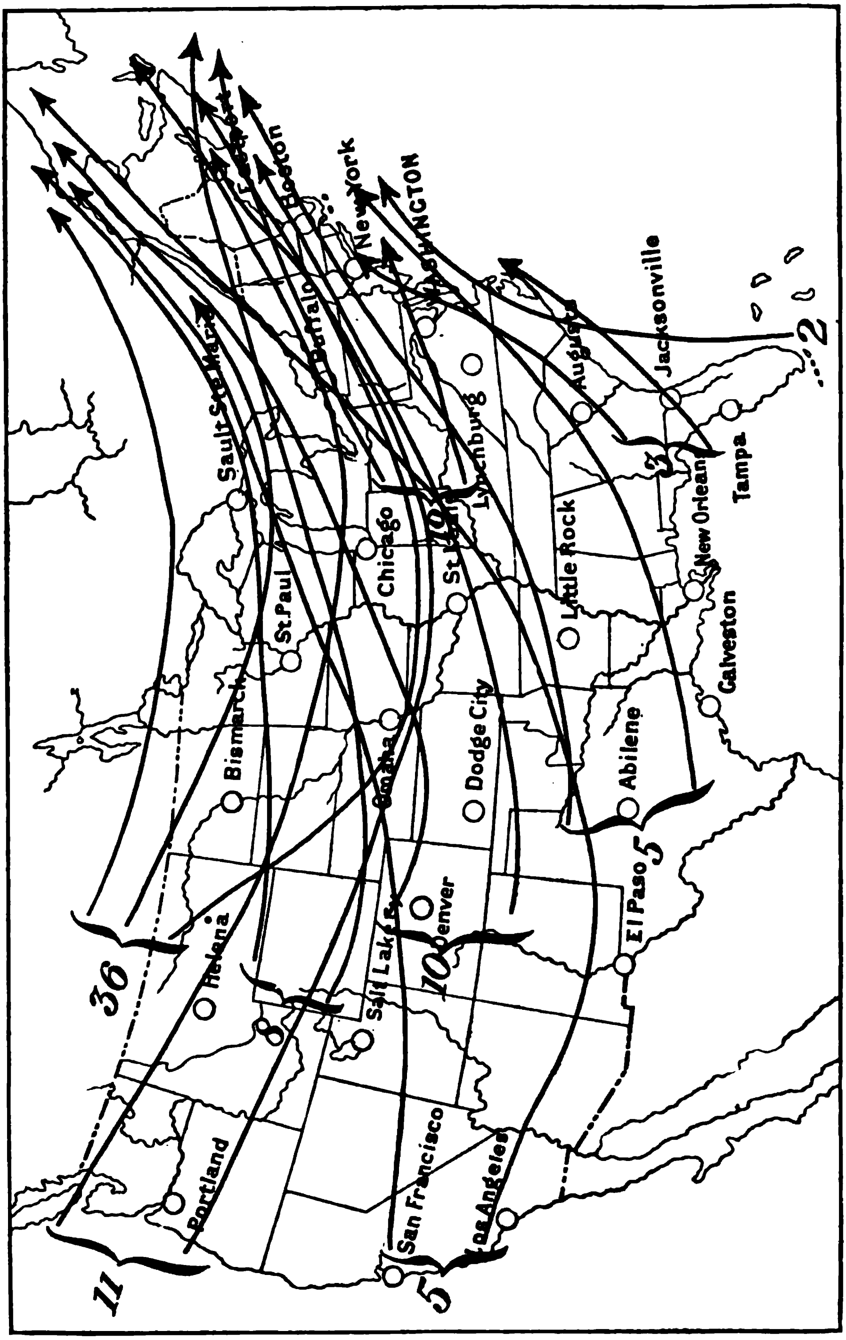

Chart 14.—Storm tracks for May.

from the Northern States about the end of the month. The tendency to form low areas in the Rocky Mountain region, sometimes quite free from precipitation, is increased, the sporadic character of the rains is pronounced, the eastward drift is much slower, the storm tracks seek more closely the northern circuit, and generally a flatter system of weather types prevails. A count of the number of storm tracks in May for the years 1884 to 1893, inclusive, shows that 36 originated in the Alberta district, 11 on the North Pacific coast, 8 on the northern Rocky Mountain plateau, 10 in Colorado, 5 in Texas, 3 in the east Gulf States, 10 in the central valleys, 5 on the South Pacific coast, and 2 in the West Indies. The tracks pursue the same general course to the Gulf of St. Lawrence, only with much less looping southward on the Rocky Mountain slope.

JUNE.

LOCAL WEATHER CONDITIONS.

The entire weather system of the United States has fallen in intensity by the month of June to the flat and stagnant state that characterizes the summer months. In accordance with the prevailing continental conditions, the interior is overheated relatively to the coast districts, and therefore low areas prevail in the central valleys, especially in the Rocky Mountain slope, while the highs tend to dominate the coast districts. The violent expulsion of high areas of cold, dry air from the interior to the coast in the northern and the southern circuits has subsided into the occasional highs that drift slowly across the country, bringing showers and cool weather with them. The heavy, overcast skies of April and May, with rainy weather, have changed into local showers, thunderstorms, and tornadoes, all the products of a vertical rather than a horizontal circulation of air. In the winter and spring the precipitation is confined closely to the periphery of the highs, but in the summer the showers are very likely to occur within the high areas as well.

The storm tracks are now much more simple, being confined to the northern circuit and the feeders that come from the south and southwest. The looping downward to the south along the mountain slope has almost ceased to be important. Many storm tracks, instead of persisting to the Gulf of St. Lawrence, die out in the middle districts and curl about in an erratic, feeble manner. A count of the storms in ten years shows that 24 began in Alberta and the Saskatchewan Valley, 7 on the North Pacific coast, 20 on the northern Rocky Mountain plateau, 14 in Colorado, 4 in Texas, 4 in the east Gulf States or near the South Atlantic coast, 3 in the central valleys, and 4 on the South Pacific coast. The great majority begin on the eastern edge of the Rocky Mountains, showing that this elevated range has much to do with throwing the eastward drift of the upper current into these cyclonic whirls.

The tornadoes of June occur chiefly in the Mississippi and lower

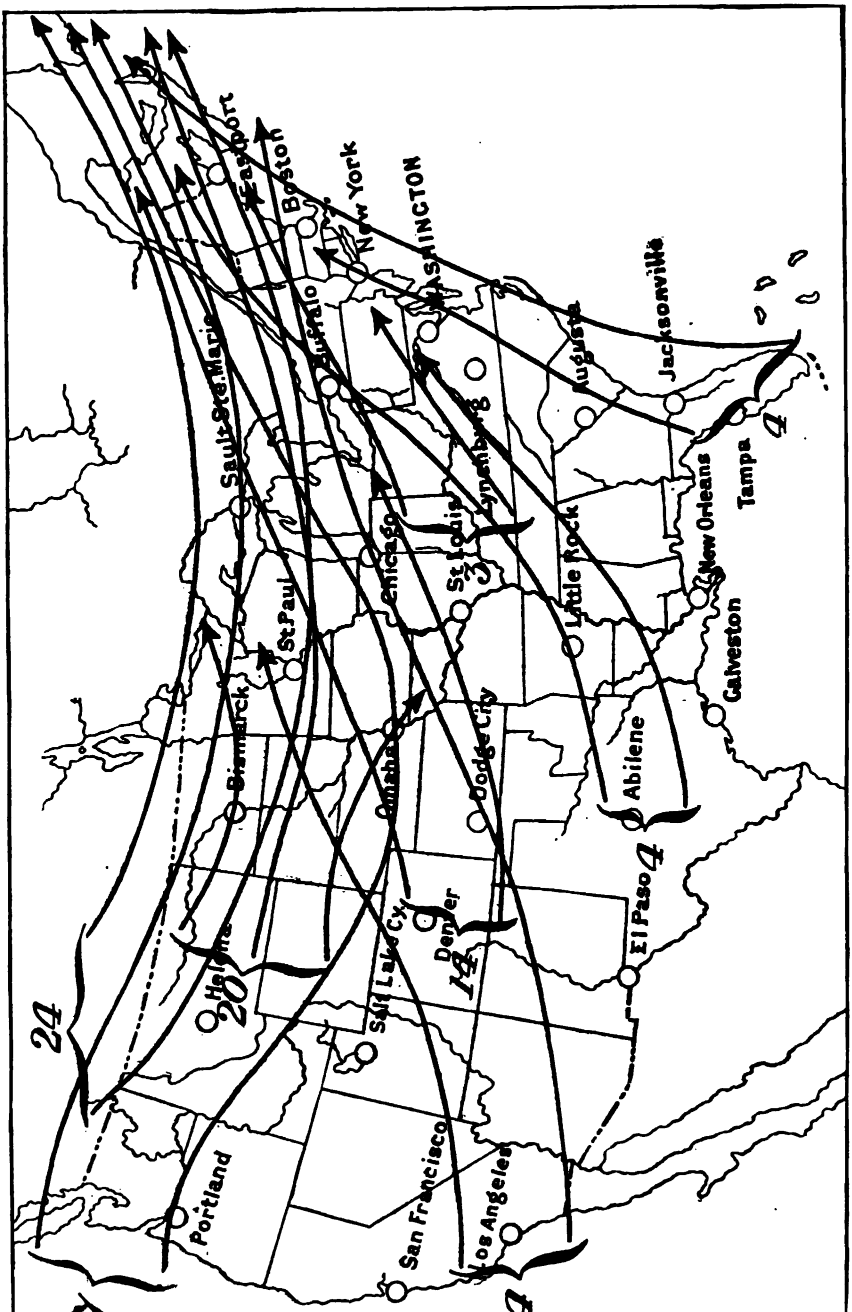

Chart 15.—Storm tracks for June.

Missouri valleys, where the humidity is high, the temperature excessive, and the conditions for local vertical circulation greatly increased. Thunderstorms are spread over the mountain slope, but especially in the Mississippi and Ohio valleys, and the northeastern districts. This indicates that the colder air derived from the northern circulation has much to do with this form of precipitation and sudden downflow of cold air from the upper strata of the air.

JULY.

STORM TRACKS AND WEATHER CONDITIONS—FORMATION AND CHARACTERISTICS OF TORNADOES.

A count of the storms of July originating in the several districts of the United States shows that they reach their maximum number in Alberta, that is, in the midst of the great storm track, and that the rest are scattered about in a very irregular manner, indicating that there is no strong prevailing impulse to control their formation. Thus we find in a ten-year period 41 in Alberta, 4 on the northern Rocky Mountain plateau, 8 in Colorado, 1 on the North Pacific coast, 6 on the South Pacific coast, 2 in the South Atlantic and East Gulf States, 3 in the West Indies, and 17 in the central valleys and the Lake regions.

Only a few storms survive long enough to pass across the United States. Those originating on the Pacific coast are likely to dissipate in the central valleys, and some forming east of the mountains on the slope are liable to disappear near the Lakes; those, however, which commence in the central valleys will probably reach the North Atlantic coast or the Gulf of St. Lawrence. All these features point to local and minor weather features, which indeed characterize the month of July, being in the midst of summer.

At this time, when the warm weather is at its maximum, the continental conditions are most fully developed. The interior of the country is heated, the ocean districts are comparatively cool. The great Atlantic high area, produced by the general circulation, protrudes upon the southeastern districts; in the same way the Pacific high overlays the northwestern districts of the mountains. Hence, between these in the Mississippi and Missouri valleys, there is a region of encounter for the southern winds produced by the Atlantic high and for the northern winds maintained by the Pacific high. The southern winds are warm and charged with aqueous vapor; the northern winds are cool and comparatively dry. The meeting of these two types of winds in the central valleys, the same conditions also extending along the Ohio Valley to the lower Lakes, is attended by two or three typical local effects. In the first place, there are calms at intervals, local pools of stagnant atmosphere, into which these opposing currents have not penetrated; in the second place, the intense radiation of the sun superheats the strata of air near the ground and causes relatively unstable equilibrium, with its tendency to overturn the strata in a vertical direction;

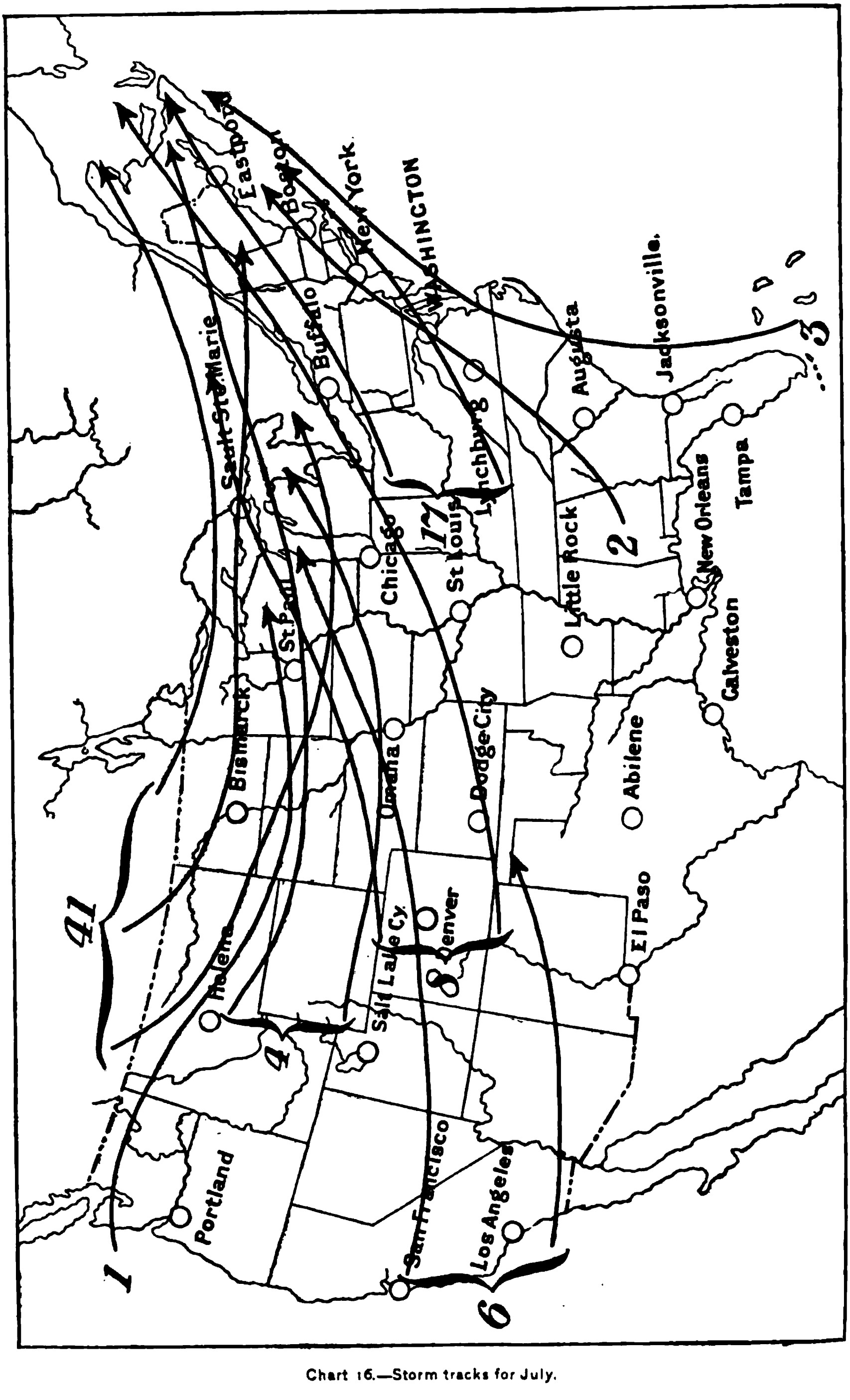

Chart 16.—Storm tracks for July.

in the third place, the cool currents from the north, borne aloft in the general eastward drift, tend at times to overlay this stagnant atmosphere in the ground stratum and to increase the unstable equilibrium.

These are the conditions that always favor the formation of local storms, tornadoes, thunderstorms, and showers, in which precipitation generally occurs during the summer. Masses of air of different temperatures in the great north and south currents may thus approach a stagnant and calm region, such as the later hours of the afternoon develop, the increase of cloudiness being merely a symptom of the existence of rising and cooling currents which portend a storm, and finally set the entire mass into a mixed congested circulation. The cold air comes down and the warm air rises, but they both resist mixing intimately. Rather they tend to be drawn out into long bands or ribbons before such mixing is accomplished, and these are the conditions for local showers. When the condensation is rapid in the strata a mile high, the formation of thunderstorms with electric discharges is accomplished. In certain peculiar formations of the circulation a tornado tube is projected downward. This is a simple vortex, and obeys the laws of the movements of fluids in gyratory circulation. If a mass of air 6,000 feet in diameter is rotating at a half mile level and it runs into a vortex so that the tube is 100 feet in diameter, and supposing the outer edge of the upper vortex makes 7 miles an hour, then at the rim of the bottom of the vortex we should have a velocity of 200 miles an hour. This causes an enormous centrifugal force in the lower tube, a high vacuum, and low temperature. It is maintained only by a forward movement of the entire vortex system. The vacuum tube causes the explosive and disastrous effects upon objects in its path, as noted in the tornado incidents, the wind at great velocity prostrates every obstacle, the cold generates the sheath of vapor that makes the tube visible like a thin skin, the same sudden condensation causes electric discharges, just as in thunderstorms on a large scale. There is no real mystery about the formation of tornadoes or respecting their terribly destructive power. It all goes back to the same principle that discharges a gun, in which case there is a sudden formation and expansion of gas; but in the tornado it is the reverse process, namely the sudden production of a vacuum into which outside air discharges itself, that is, into the hollow vortex tube, and with the other result of quickly cooling the heated air drawn into the tornado vortex.

There is no available way of avoiding the occurrence of tornadoes in the weather conditions favorable for them. The tubes resist an explosive discharge in the air outside it, these having often been fired upon by cannon at sea. They sweep through a forest as readily as through a city. There seems to be no increase in the annual number of them. Some have sought to connect their recurrence with the sun spot frequencies, and it is possible that there is some indirect connection, just as in all the other weather elements, but only through the features of the general weather circulation. If this is stagnant over large regions, then the tornado conditions will most readily develop. At present they can only be roughly forecasted as "conditions favorable for local storms." It may result from a better knowledge of the relations of local conditions to general circulation that improved forecasts may yet become possible, but this can be the product only of very extensive research and investigation.

The excessively hot spells of weather that cover the Atlantic States during certain intervals are attended by a high area on the South Atlantic coast, being a portion of the great subtropical high. Aside from the transportation of warm air from southern to northern latitudes, there must be a downpouring of dry, hot air in the high itself, due to the excessive "potential" temperature of the upper strata. How these layers become overheated is a question to be solved by a study of the general circulation of the air.

A summary of the number of storms developing in the several regions, marked off by the natural physical features of the United States as recorded in this bulletin is appended, and a glance at it will enable one to recall many of the statements that have been introduced regarding the weather of the several months.

Summary of the local origin of storms by districts for the ten years 1884–1893.

No.	Names of the geographical groups.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual group sums.
1	South Pacific coast	2	2	....	....	5	4	6	....	....	3	1	....	21
2	North Pacific coast	20	18	28	23	11	7	1	....	13	18	17	28	184
3	Alberta	32	27	39	24	36	24	41	45	39	36	35	49	427
4	North Rocky Mountain plateau	8	8	8	8	8	20	4	4	5	12	4	10	99
5	Colorado	10	13	12	13	10	14	8	8	7	11	5	14	125
6	Texas	21	18	14	13	5	4	....	2	8	4	12	8	109
7	East Gulf and South Atlantic	2	6	6	10	3	4	2	4	4	9	11	8	69
8	West Indian	....	....	....	....	2	....	3	12	7	14	6	....	44
9	Central	3	7	....	....	10	3	17	8	....	3	12	....	63
	Monthly sums	98	99	107	91	90	80	82	83	83	110	103	117	1,143

WEATHER CONDITIONS AT WASHINGTON, D. C., FOR THE TWENTY-SIX YEARS 1871–1896.

It is important to compare the relations of the meteorological elements at each station, as these vary in the seasons and from year to year. A condensed statement for Washington, D. C., covering the period 1871–1896 is given as an illustration of the kind of extremes and differences that may be expected at this place.

Statement of averages, etc., at Washington, D. C., for the twenty-six years 1871–1896.

Weather conditions.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Temperature:												
Mean or normal	33	36	41	53	64	72	77	74	68	57	45	36
Warmest month—												
Year	1890	1890	1878	1878	1880	1874	1876	1872	1881	1881	1896	1889
Degrees	44	43	49	58	70	78	81	79	77	63	51	46
Coldest month—												
Year	1893	1885	1885	1874	1883	1878	1891	1874	1871	1876	1880	1876
Degrees	25	27	34	48	59	69	72	72	62	51	40	26
Highest—												
Degrees	76	78	83	93	96	102	103	101	104	92	80	73
Day	12	23	22	18	26	9	18	13	7	3	13	4
Year	1890	1874	1894	1896	1880	1874	1887	1881	1881	1879	1879	1893
Lowest—												
Degrees	−14	−2	4	22	34	46	53	49	38	26	12	−13
Day	1	5	4	19	1	1, 6	20, 22	24	26	31	22	31
Year	1881	1886	1873	1875	1876	1873 1894	1890	1890	1879	1893	1880	1880
Frost:												
Average date first killing frost (in autumn)—												
Day										22		
Average date last killing frost (in spring)—												
Day				14								
Precipitation:												
Average monthly	3.50	3.31	4.08	3.16	3.90	4.29	4.84	4.44	3.82	3.27	2.88	3.01
Average number days 0.01 inch or more	12	11	12	11	12	11	11	12	9	9	10	11
Greatest monthly—												
Year	1882	1884	1891	1889	1889	1883	1886	1875	1876	1885	1877	1878
Amount	7.09	6.84	8.84	9.13	10.69	8.55	10.63	12.93	10.81	8.69	7.18	4.94
Least monthly—												
Year	1872	1872	1894	1896	1875	1873	1872	1892	1884	1874	1890	1889
Amount	0.23	0.93	0.98	1.07	1.01	1.63	0.82	0.85	0.14	0.29	0.79	0.19
Greatest amount in twenty-four hours—												
Amount	2.28	2.29	2.79	3.21	3.50	4.16	5.80	2.84	5.66	3.98	2.83	2.70
Day	4	5–6	9	26	7–8	22	29–30	29	15–16	4	24	17
Year	1886	1896	1881	1889	1886	1886	1878	1875	1874	1877	1877	1888
Greatest amount snowfall in twenty-four hours—												
Amount	5.0	10.0	6.0	4.0						(*a*)	2.5	10.0
Day	12	3	11	6						23	5	26
Year	1893	1886	1888	1889						1889	1891	1890
Weather:												
Average number of days—												
Clear	7	7	8	9	10	9	10	10	11	12	9	9
Partly cloudy	12	11	12	12	12	15	14	13	11	11	12	12
Cloudy	12	10	11	9	9	6	7	8	8	8	9	10
Wind:												
Prevailing	NW.	NW.	NW.	NW.	S.	S.	S.	S.	S.	S.	NW.	NW.
Highest velocity—												
Miles	46	60	48	43	54	48	60	53	66	51	54	49
From	NW.	NW.	NW.	NW.	SW.	S.	NW.	N.	SE.	NW.	SW.	W.
Day	30	2	24	3	28	26	4, 28	5	29	4	23	9
Year	1894	1876	1878	1879	1896	1877	1874 1877	1878	1896	1877	1891	1876

a Trace.

CIRCULATION OF THE ATMOSPHERE IN THE UPPER LEVELS—THE INTERNATIONAL CLOUD OBSERVATIONS.

In these papers much has been written about the cyclonic circulation at the surface of the ground, but the subject would be very incomplete without alluding to the efforts that are being made to determine the circulation of the upper atmosphere all over the globe. Theoretical solutions, to some extent confirmed by observations, have been given, and yet the true connection between the general and the cyclonic circulation has not been properly cleared up and tested by experience. So far as the general movements are concerned, the components are somewhat as follows in the northern hemisphere, those south of the equator being counterparts; along the meridian from latitude 24° to the equator the component is south, to the pole it is north; in middle latitudes, where the extra tropical cyclones prevail, there is a southern component in the middle cloud strata, and two northern components, one near the ground and one in the cirrus strata. Along the parallels of latitude there are two systems of components; from 0° to 35° latitude a westerly component at the surface, and an easterly in the higher layers; from 35° to 90° latitude two easterly components, making a maximum and rapid eastward drift in the neighborhood of 54°. In the vertical, from 0° to 20° and from 70° to 90° latitude, there is an upward component; from 20° to 70° latitude a downward component. The cyclonic and the anticyclonic motions to some extent spring out of these, but the really active part of them is confined to the strata within 2 miles of the ground, and yet the precise course of the stream lines is not comprehended throughout their extent.

Much light has been thrown upon the obscure features of these problems by observation at high altitudes, and especially by measurements of cloud heights and velocities, but still much remains to be done to reach satisfactory conclusions. It is thought that some account of these international cloud observations, and a reference to the important literature regarding them, may be of interest to those who have these subjects at heart, especially those who are cooperating in the work of the Weather Bureau.

The attention of meteorologists in the early developments of the subject were naturally almost exclusively confined to studies on the data furnished by the lowest stratum of the atmosphere. The circulation and physical conditions of the air in the higher strata were investigated to some extent by means of the theoretical considerations and the general movements of clouds. It has, however, become apparent that a scientific knowledge of the action of the currents in cyclones and anticyclones can be obtained only by a determined attack upon the physics of the upper levels of the atmosphere. Progress in meteorology, working along the original lines at the surface of the ground, has for a number of years been disappointing, and it is well known that in the art of forecasting almost exactly the same methods that were perfected twenty years ago are still employed. There seems to be little hope of improving this state of affairs unless a radically new way of dealing with the data can be devised which will efficiently supplement the system now in use.

The Chief of the Weather Bureau has expressed the opinion that there are two or three lines of investigation promising the wished-for results. One is the practical development of knowledge regarding the polar magnetic energy from the sun. The serious difficulty in the way of doing this has been the expensive and complicated nature of first-class magnetic observatories, which must necessarily limit the number in the United States. What we need is a simple, inexpensive, and yet reliable instrument that can be utilized as readily as a barometer, thermometer, or a watch. It seems now, after a couple of years of trial, that such an apparatus is in hand, and a record of its performance was published, with a description of it, beginning in the January number of the Weather Review for 1896.

Another process for getting at the action of the upper air is the transportation of barometers, thermometers, and other apparatus into the higher levels. This can evidently be done by mountain stations, balloons, and kites, and experiments are being conducted by the Weather Bureau to carry out this purpose as far as practicable.

A third line of investigation is the study of the clouds in all their aspects; the conditions under which the several forms are developed; the heights of the several levels, the variations of the same in the diurnal and annual periods, and particularly in connection with the cyclonic circulation of the lower strata; the direction and velocity of movement in the general circulation of the currents of the atmosphere as well as around the barometric maxima and minima. The fact that clouds are present almost every day in a series of forms which pass from one to the other by delicate gradations, each of which must indicate specific physical properties, shows that this is a very rich field of research which has been only imperfectly cultivated. Many interesting conclusions have been developed by observers of such phenomena in the past fifteen years, but only during the last five years has the conviction become general that this is one of the most important studies for the practical meteorologist.

With the view of reducing the details to uniformity of method and to secure cooperation among the observers in different countries, an organization has been completed which went into effect last spring. A brief history of the movement is as follows: The measurement of cloud heights is an old problem, and many devices have been invented for the solution of the practical difficulties, of which a full account may be found in the Report of the Chief Signal Officer, part 2, 1887, by Prof. Cleveland Abbe. More or less systematic observations, extending over considerable periods of time, have been made at Berlin, Upsala, Storlien, Kew, and Blue Hill (Mass.), by methods depending upon triangulation. Besides the simple trigonometric formulæ, another system for computing the shortest distance between the two sight lines, devised by Ekholm and Hagström, Upsala, also a process for reducing the points on a photograph plate exposed in a photogrammeter by Åkerblom, Upsala, have been successfully used and are recommended as the best known.

The following are the leading papers on cloud observations:

1. Mesures des hauteurs et des mouvements des nuages, par N. Ekholm et K. L. Hagström, Upsala, 1884.

2. Des Principales méthodes employées pour observer et mesurer les nuages, par Hildebrandsson et Hagströn, Upsala, 1893.

3. De l'emploi des photogrammètres pour mesurer la hauteur des nuages, par Åkerblom, Upsala, 1894.

4. Observations made at the Blue Hill Meteorological Observatory, Annals Harvard College, Vol. XXX, Part III, by H. H. Clayton and P. S. Fergusson, 1892.

At the international conference, Munich, 1891, a committee was appointed to consider the question of concerted observations on the direction of motion and the height of clouds. This committee recommended that observations on the direction of motion and the height of clouds should be commenced at certain stations distributed over the globe, and continued for one year; that short instructions be prepared for these observations; that the scheme of cloud classification put forth by MM. Hildebrandsson and Abercromby be adopted, and a cloud atlas illustrative thereof be published.

As the result of these propositions, the cooperative international cloud observations began May 1, 1896, and will continue one year. As far as known, the theodolite method will be employed at Washington, D. C., Blue Hill, Mass., and Christiania; the photogrammeter method at Upsala, Paris, Potsdam, St. Petersburg, Nijni Novgorod, Manila, Batavia, Melbourne, and probably Kew, Calcutta, and Sydney. The difficulty in cloud observations is to have two observers, separated by a base line nearly 1 mile long, set their sight lines on exactly the same point of a rapidly moving and dissolving cloud. The advantages of the theodolities is that the instruments are cheaper, many more observations can be taken with the same labor, and the calculations are the briefest possible by any method. The observations that must be rejected at the outset can be determined by a small platting machine, being a model of the real base line and instruments, such as the one invented by H. H. Clayton, at Blue Hill. Photographs, on the other hand, possess the advantages of giving definitely the point on the cloud, but the difficulty of securing photographs of all kinds of clouds in all weather is very great and the cost of the work much more for the same number of individual observations. The international classification of cloud forms being issued, it was adopted by the Weather Bureau. It went into operation July 1, 1896, throughout the service, and suitable instructions and illustrative forms were prepared for the observers. The atlas of cloud forms issued by the international conference committee is now ready for distribution, and may be purchased of M. Teisserence de Bort, Bureau Central Météorologique, 176 rue de l'Université, Paris, France.

Besides the observations with theodolites and photogrammeters for the actual heights and velocity of motion of clouds at the primary stations, a number of secondary stations for the relative motions and the other available data will be established in each country. In the United States there will be twelve such stations under the immediate control of the Weather Bureau, equipped with nephoscopes for the observations. It is very desirable that the network of the stations be made as complete as possible in all parts of the country, and it is hoped that this opportunity for cooperation may be embraced by other persons willing to do some valuable scientific work. The colleges might profitably instruct their students in such observations at a very moderate expense. A first-class nephoscope can be made for $20, and serviceable ones at lower rates. The observations would require half an hour's work three times a day, between 8 and 9 a. m., 1 and 2 p. m., and 5 and 6 p. m. The Weather Bureau will furnish suitable instructions to observers, and will aid them as far as possible in explaining the very simple computations that would be needed to prepare the observations for final discussion.

There are many forms of nephoscopes in use, but the one devised by Professor Marvin, of the Weather Bureau, seems to be especially well adapted to the requirements. A description of it appeared in the January, 1896, number of the Weather Review. It may be said in this place that its best feature is the device for keeping the sighting knob exactly 12 centimeters above the mirror in every possible position, so that the unit of height becomes 1,000 meters, and the velocity in meters per second at that height is just one-third the number of millimeters passed over by the image in 25 seconds. This makes the computations very easy, and when the height of the cloud level is known from the theodolite work the actual velocity is obtained by simply identifying the cloud observed from its form as belonging to such a level. The mean of a large number of observations gives a true velocity. The base line at Washington is about 1,360 meters long, one end on the Weather Bureau building and the other on the War, State and Navy building. The ratios of velocity by the theodolites and nephoscopes at this station in the different cloud levels give the means of using other nephoscope observations, provided the naming of the cloud forms is carefully done.

The ultimate problem is to obtain the coordinate velocities of the several components in the general circulation and the relation that these have to the cyclonic circulations which depend upon them. The importance of these solutions to the art of forecasting, and the fact that voluntary observations made in widely separated parts of the United States are needed as contributions to the network, together with the simplicity that pertains to nephoscope work, induces the hope that some interested in the physics of the air may take up the task of cooperation.

DESCRIPTION OF THE SOLAR MAGNETIC PERIOD OF 26.68 DAYS AND ITS RELATION TO THE FORMATION OF STORMS IN THE NORTHWEST—DEFINITIONS OF THE TERRESTRIAL MAGNETIC ELEMENTS—SOLAR MAGNETISM AND ITS CONNECTION WITH THE WEATHER.

A careful study of the succession of the highs and lows in the northwest has revealed the fact that there is a peculiar curve which they try to follow in their intensity, and that they tend to repeat the same curve every 26.68 days. This curve has a grand sweep with two maxima and two minima in it, and ten minor crests spread along it in quite a symmetrical manner. The next striking peculiarity of the eastward drift is that the succession of the highs and lows is along this curve in one position, and then along the same curve when it is inverted or turned over. This inversion is found to occur at uncertain intervals, and yet in such a way as to be certainly connected with the motion of the earth about the sun.

These considerations point to some kind of energy that comes from outside the earth, falls upon the whole hemisphere, and is associated with the sun's action. Finally, when the great preponderance in the number of storms in North America over the corresponding localities in Asia in the middle of the continent is considered—the number in America being about ten times as great as in Asia—it is necessary to look for some cause that accounts for this difference. The preponderance of storms in North America, the inversion of the order of their production, the alternate hastening and slowing up of the eastward drift, are facts of profound meaning in seeking the fundamental laws regarding the origin of storms.

A study of the variations of the magnetic field of the earth has brought out a new series of facts that seem to be very closely connected with those just mentioned. It is shown that a field of force is impressed upon the earth in directions that nearly coincide with the magnetic meridians. When this force increases, an impulse is propagated from the north to the south, and in case of unusal disturbance the magnetic and electric field of the earth suffers perturbations or storms that show themselves in an outburst of beautiful auroral light or in the electric earth currents that temporarily impede telegraphic communication.

An examination of the places of the relative frequency of the auroras shows that there is a maximum belt running from Alaska over the southern portion of the Canadian possessions, near the lower end of Hudson Bay, over Labrador, thence to the north of Norway, Sweden, Siberia, till the circuit is completed. In shape it is a rude oval, embracing the geographical pole and the magnetic pole, which is located near Boothia Island. The center of the outspreading magnetic force just mentioned is midway between these poles, and its meridians are perpendicular to the auroral ovals all over the hemisphere.

This force is at a maximum over the auroral belt, sinks away somewhat to the north, and falls rapidly to the south. Now it is known that the aurora, this magnetic force, and the sun spots all rise and fall together in intensity in the eleven-year period. This is another clew to our supposition that storm action is dependent upon the solar output, transmitted in long, wide sweeping magnetic curves, and falling upon the polar regions of the earth, the sunlight meanwhile radiating to its tropical zone.

Another group of facts of more detailed nature indicate the same conclusion. A study of the curves of change in the 26.68-day periods show that the same variations can be traced throughout the magnetic fields of Europe, Asia, America, and Australia, the impulses being common to the earth. It is found that the temperature and pressures of the northwest have the same pulsation, which arrives in the Dakotas in one day after the magnetic change has taken place. This same curve, on applying the period through a long series of years, is discovered to be the type in which the sun spots tend to group themselves, the southern hemisphere being the direct type and the northern hemisphere the inverse type. This implies that the period 26.68 is that of the rotation of the sun's nucleus, and it agrees very closely with the time computed for the visible surface at the equator from the motions of the sun spots.

The inferences follow that the sun is an immense magnetic sphere, like the earth, the north pole positive and the south pole negative; that it sends out great waves of force which reach the earth in the disturbances; that the field of the sun is maintained at different strengths in the several meridians, and that as it turns around on its axis this field at the earth makes corresponding impressions upon the earth's field. A magnetic curve is like a delicate spring, and those from the earth and sun touch and bend in response to each other in the most wonderful manner. Hence all these observations at the earth, pursued for fifty years by the magneticians, are measures of the solar energy, and will some time be so interpreted as to become of great use to the world.

There is still another system of correspondencies between the magnetic and the meteorological actions. On taking mean values for a long series of years in the European magnetic field and the Dakota pressures and temperatures it is seen that these rise and fall in a very peculiar curve, which is that of the sun-spot areas fundamentally, with a shorter period, one-fourth of eleven years, superposed upon it. The persistence in this synchronism is such as to exclude anything like an accidental relation, and this summary embraces seventeen years.

A close computation on the position of the storm tracks in the United States shows that they rise and fall in latitude in the same long curve; also the speed of the eastward advance, the rate of propagation, changes in the same proportion; the intensity of the storm action, the amplitude of the highs and lows, and hence of the barometer and thermometer readings, give the same relative curves.

In all cases we have the unequivocal testimony presented that an increase of this polar magnetic energy increases the pressure, diminishes the temperature, changes the order of the production of storms upon inversion, their ntensity, their speed of eastward movement, the position of the tracks, and generally precedes all the principal conditions known to exist in the elements of the physics of the atmosphere.

The last point to answer, why the storms preponderate in North America in number rather than in Asia, is simply because the magnetic pole happens to be on this side of the geographical pole, causing the concentration of energy to take place in the midst of the North American continent, but to the northward of Asia. This condition of affairs tends to build a high-pressure belt over western Canada, just along this auroral belt where the magnetic energy comes down, and the continual interchange of power shows itself by stripping off a rapid succession of storms to the northwest of the United States, while in Asia a great undisturbed high prevails in winter and an immense low in the summer.

The correlation of such a vast system of facts, unbroken by any known contradictory evidence, leads to the belief that the solar energy reaches the earth in two ways—one along the ecliptic and the other perpendicular to that plane. A very plausible theory of the glacial ice waves is that during long periods the sun's magnetic output was increased, and that in consequence, as shown above, the temperatures of the arctic regions were greatly lowered. Hence it may easily be perceived that this new discovery of the Weather Bureau opens up a fascinating field of study into the great laws of the solar system, and that it may well be called a new chapter in cosmical astronomy.

It is known that the usually accepted system of meteorology indicates that a low-pressure belt should prevail along the northern borders of the United States, but as matter of fact high areas frequently form in that region and drift eastward in the northern circuit. In order to explain these apparent anomalies, it is suggested by the facts herein mentioned that the cooling tendency in the atmosphere along the auroral belt just to the north of the northern circuit is in part due to the action of the polar magnetic energy falling on that region. This facilitates the descent of the air of the upper strata to the lower, thus accelerating the turning of the air moving northward in the upper strata into the returning current moving southward in the lower strata, as the general theory of circulation requires. The North American highs are made by the air turning in direction from north to south and descending to the surface of the earth.

The great importance of understanding the cause of the formation of the winter highs in the extreme northwest, and also those proceeding from the district to the south of Hudson Bay and advancing thence to New England, is apparent to every forecaster. Upon the energy and rate of movement of these northern highs the whole aspect of the forecasts depends.

The connection between the magnetic forces of the earth and the sun and the meteorological elements of the earth's atmosphere have been shown to be so intimate that it is desirable to have an understanding of the meaning of the leading words used in the science of terrestrial magnetism in order at least to follow the statements made in this subject. The nomenclature grew up in consideration of the behavior of a freely suspended magnet rather than with regard to the wider aspects of science that have since been developed, and hence the choice of reference directions is limited to practical rather than to the best possible system. In the northern hemisphere a freely suspended needle dips with its north-seeking end beneath the horizon and inclines to the west of the geographical meridians, taken as a whole over Europe, where the science was first studied. This needle will hang tangent to the line of force determined by the earth as a magnet at the station considered, and there have consequently been employed two systems of coordinates to define the force of the magnetic field at the point of suspension.

(1) The first system of coordinates is—

F, the *intensity* of the magnetic force of the earth.

D, the *declination*, positive west from geographical north.

I, the *inclination*, positive below the horizon.

These give the exact direction and magnitude of the magnetic force.

(2) The secondary system of coordinates is—

H, the *horizontal component*, positive north along the magnetic meridian.

D, the *angular declination*, positive west.

V, the *vertical component*, positive downward.

These also determine the *vector*—that is, direction and magnitude—of the magnetic force.

If the earth's magnetic field were permanent, these values of F D I or H D V would be constant at every station on the globe. But they are all continually fluctuating in several periods—the diurnal, the solar, the annual, and the secular.

The *diurnal period*, twenty-four hours, is due to the rotation of the earth on its axis, changing the components of the earth's normal field in relation to the external magnetic lines of the force in the ether as induced by solar action.

The *solar period*, 26.68 days, is due to the rotation of the sun on its axis, carrying with it the *coronal* magnetic field, which it continuously sustains, with an intensity varying along the solar meridians, and also as a whole in the solar eleven-year period.

The *annual period*, 365.25 days, is due to the earth's motion about the sun in its orbit, which changes the aspect of the sun's magnetic system relatively to that of the earth, as the sun moves in declination with the seasons.

The *secular periods* are but little understood, but there are several of them: (1) The eleven-year period, due to the slow workings of magnetic masses within the solar nucleus; (2) the longer period of five hundred to one thousand years, differing in the several parts of the earth, and due to the slow redistribution of magnetism within the earth, and (3) the very long secular periods of the sun as a variable star by which the terrestrial system must be affected, just as it is in the shorter periods.

To study the causes that modify the earth's normal magnetic field in these several periods it is necessary to disentangle the superposed forces from the normal field, in order to have the components of the *deflecting forces* at any time. The simplest way of doing this in practical work is to take the magnetic meridian at a station as the plane of reference with—

X, positive to the magnetic north.
Y, positive to the magnetic west.
Z, positive to the magnetic nadir.

Hence, *variations* in the horizontal force △H, in the declination △D, in the vertical force △V, may be combined into a horizontal component σ, which makes an angle β on the horizon plane with the magnetic north, and also into a total vector force s which makes a vertical angle α with σ, and an angle β between its plane and that of the magnetic meridian. In Chart 17

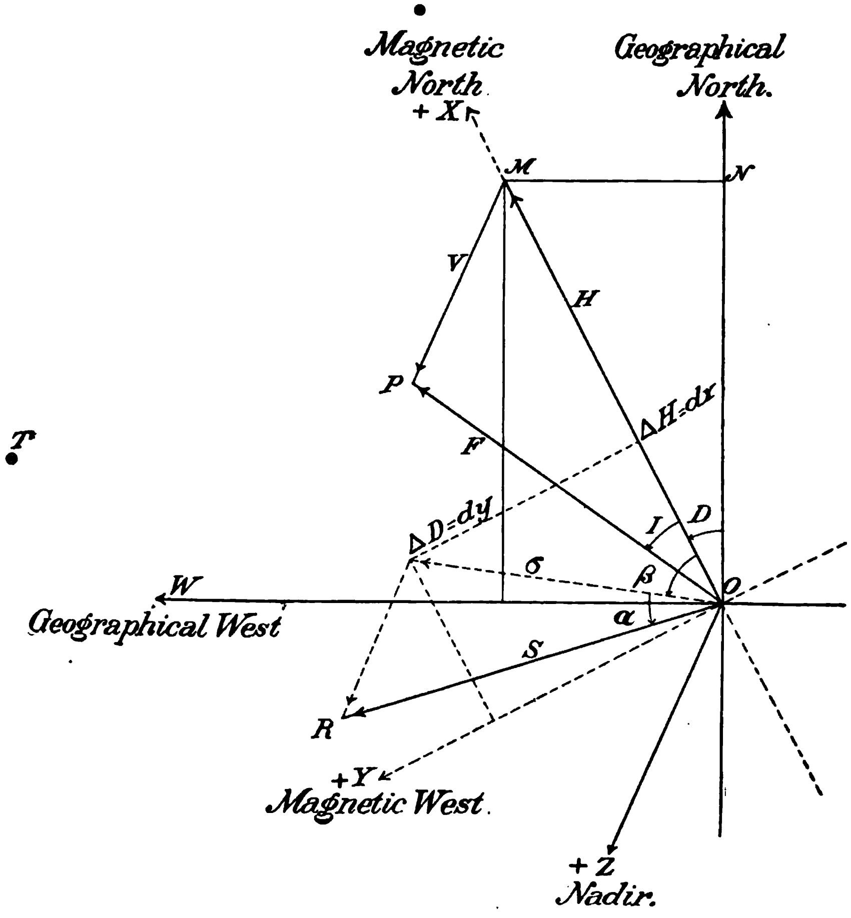

Chart 17.—Coordinates of normal and deflecting magnetic forces.

O N is geographical north, O W west, O Z nadir.
O P = F, N O M = D, M O P = I. First system.

$OM = H$, $NOM = D$, $MP = V$. Second system.

σ is the resultant of $\triangle H = dx$ and $\triangle D = dy$, and makes the angle $\beta = \triangle H O \triangle D$ with the magnetic meridian.

s is the resultant of σ and $\triangle V = dz$ and makes the angle $\alpha = \triangle DOR$ with σ. The vector sum of O P and O R is O T, and therefore O T gives the direction of the needle and the intensity of the magnetic force at the time considered.

For many years it has been known that there must be a close physical connection between the sun and the earth because of the definite fluctuations in intensity between solar and terrestrial phenomena. The investigation of this subject has shown that the transference of energy is not only along the ecliptic, but also in widespreading lines which are perpendicular to the ecliptic at the earth, this circumstance indicating that the sun, as well as the earth, is an immense spherical magnet. The sun therefore emits energy along two paths to the earth and in two different forms of radiation: (1) Along the ecliptic, in *electromagnetic* waves, wherein the vibration is in planes perpendicular to the line of propagation; (2) in *magnetic curves*, wherein the ether motion is probably rotatory, which is called the *coronal* field because of the intimate relation of the lines of the solar corona to magnetic lines of force.

When the coronal magnetic field approaches the earth perpendicular to the plane of the orbit, the lines of force are disturbed and their direction changed to enter the surface at such angles as correspond to the *permeability* and to the shape of the permeable mass. The result of the computation is that the earth acts like a permeable shell, such as soft iron which can be magnetized by induction, and the magnetic curves conform to a permeability 2, and to a depth of shell of 800 miles. Near the poles the curves are swept to the side, and concentrate in the auroral belt, or ovals, which surrounds the magnetic and the geographical poles; also other magnetic lines are crowded together in the Tropics. In the latitude of the United States the field is thinner and somewhat confused, owing to the interplay of the polar and the tropical fields. The entire field acts nearly along the magnetic meridians, except under disturbances and local distortions, but with an intensity which varies from day to day. It has been computed that there is a periodicity of 26.68 days in the coronal field, which gives a curve of relative intensity, as shown in Chart 18, for each revolution of the sun on its axis, and represents the average intensity of the solar magnetism from meridian to meridian. The curve is quite symmetrically balanced about two axes at right angles to each other, giving crests that correspond on either side in pairs. From this may be computed the primary form of the distribution of magnetism within the solar nucleus. The period is almost exactly that of the sun's visible surface at the equator, as determined by observations on the sun spots.

A very laborious discussion of this coronal magnetic field at the

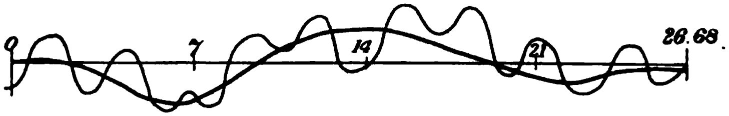

Fig. 1. Direct type of Solar Magnetic Field.

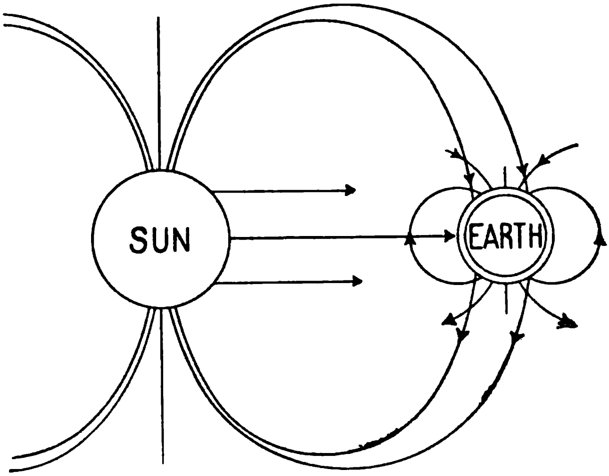

Fig. 2. The Sun's Coronal Magnetic Field.

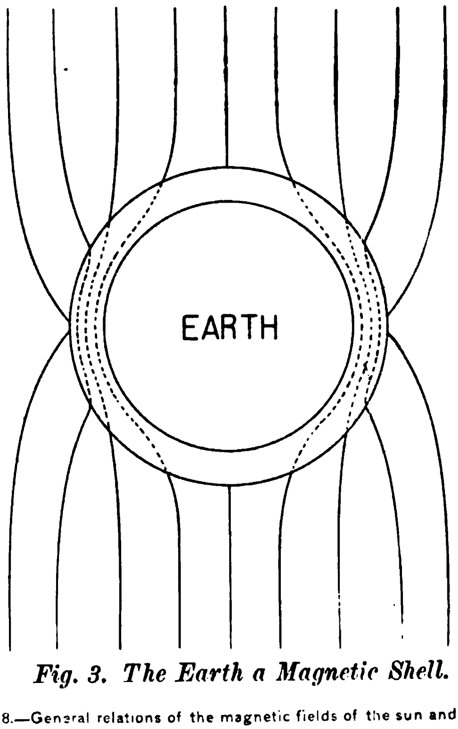

Fig. 3. The Earth a Magnetic Shell.

Chart 18.—General relations of the magnetic fields of the sun and the earth.

earth gives the important conclusion that the field is impressed in two types, that is, in the form shown in the diagram called the *direct type*, and also in the form that results from turning the curve over on its long axis, called the *inverse type*. Now the pressures and the temperatures of northwestern United States and Canada just east of the Rocky Mountains pass over a station on the average in such a way as to follow this peculiar curve, showing that the general circulation of the earth's atmosphere is to some extent controlled by this coronal impressed field which depends upon the rotation of the sun on its axis. The eastward drift, the alternate hastening and slowing up in middle latitudes, as shown by the rate of motion of the storms, are all features that apparently depend upon this polar field.

In order to account for this peculiar inversion it has been shown that the sun spots, arranged on meridians according to this period, reproduce the same curve, with the direct type in the southern hemisphere and the inverse in the northern hemisphere. The physics involved is complicated, but the inference is that the northern hemisphere of the sun is positively magnetic while the southern hemisphere is negative. The passage of the earth as a magnet about the sun involves it, in respect to the direction of the solar magnetic lines, within two systems of couples, which produce the effects observed at the surface. It has also been discovered that the law of inversion of these types involves a semiannual periodicity so disposed to the planes of the sun's and the earth's equators as to be dependent upon the earth's orbital motion with approach and recession of the magnetic poles twice each year. The vectors of magnetic force belonging to the electromagnetic or visible sunlight field have been worked out, and the results, transferred to a large globe, confirm the view that the earth acts like a spherical magnetic shell. These impressed forces explain the diurnal movements of the needle in all latitudes and are to be referred back to a complicated system of forces whose curves are distorted by the earth placed in a uniform field which is parallel to the ecliptic.

The entire subject is of great interest to the physicist and of much importance to the meteorologist. Some idea of the power of the coronal field over the atmosphere may be gained by reference to the results of a computation embracing observations of the northwest of the United States and of Europe for the years 1878–1894.

The following variations take place simultaneously:

In the maximum polar field (auroral belt), 0.000050 C. G. S.

In the European field (also United States), 0.000010 C. G. S.

In the external coronal field (near the earth), 0.000030 C. G. S.

To these correspond, when the above changes are maintained for a year, as is the case in the northwest of the United States and west Canada—

Change in the mean annual pressure, an increase, 0.02 inch.

Change in the mean annual temperature, a decrease, 2° F.

Change in the mean annual pressure amplitude, −0.01 inch.

Change in the mean annual temperature amplitude, −0.2° F.

During certain years in the Dakotas the pressure averages higher and the temperature lower; the average swing of the oscillations from high to low and from warm to cold, taken day by day, is less; and this takes place in years of increased magnetic force from the coronal field in the proportion given above.

In order to show how widely these changes occur from year to year, it is found in the sun spot cycle 1878–1890 that the following ranges took place in those districts:

Range in the European magnetic horizontal component σ, 0.000060 C. G. S.

Range in external solar coronal field, 0.000180 C. G. S.

Range in the maximum polar (auroral) field, 0.000300 C. G. S.

Range in the northwest (the Dakotas) pressures, 0.10 inch.

Range in the northwest temperatures, 7° F.

Range in the northwest pressure amplitudes, 0.06 inch.

Range in the northwest temperature amplitudes, 1° F.

Actual figures for the years 1878–1894.

Years.	European horizontal σ.	The Dakotas.		Amplitudes.	
		Pressures.	Temperatures.	Pressures.	Temperatures.
	C. G. S.	*Inches.*	*Degrees F.*	*Inches.*	*Degrees F.*
1878	0.000064	29.95	46	0.154	4.2
1879	.000071	29.98	44	.176	6.7
1880	.000084	29.98	43	.172	6.4
1881	.000087	30.04	39	.121	6.3
1882	.000108	30.05	37	.143	6.2
1883	.000090	30.07	38	.158	5.9
1884	.000098	30.04	37	.117	6.5
1885	.000094	30.06	37	.112	6.9
1886	.000088	30.02	41	.128	6.6
1887	.000071	30.03	36	.150	7.1
1888	.000073	30.06	37	.138	6.4
1889	.000068	30.04	42	.147	6.2
1890	.000050	30.04	40	.144	6.7
1891	.000083	30.03	38	.155	6.6
1892	.000101	30.05	39	.131	6.2
1693	.000096	30.00	41	.148	7.1
1894	....	30.03	42	.158	6.6

The connection between the magnetic forces and the pressures is much more clearly defined than with the temperatures, but the data should be plotted into curves and studied. The functions show that for an increase in the intensity of the solar magnetic force there results an increase in the pressures and a decrease in the temperatures, with a diminution in the pressure and temperature amplitudes. In other words, the years of greater magnetic intensity give higher pressure over the Arctic region, colder weather, more steady conditions, that is, with less range in the climatic fluctuations. The pursuit of these studies into all regions of the earth will no doubt disclose some of the hidden forces that have made weather so difficult a subject to understand and to forecast its probable conditions.

GENERAL REMARKS ON FORECASTING.

PRACTICAL WEATHER FORECASTING.

This bulletin will evidently be more nearly complete if some statements regarding the practical art of making weather forecasts for the United States are added. The difficulty of doing this successfully is considerable because of the great complexity of the material and the large element that personal judgment must necessarily play in the interpretation of any given map of the weather conditions. Yet it is believed that certain principles can be laid down which should have much influence in the improvement of anyone desiring to learn forecasting, and in the correction of imperfect notions among those already somewhat practiced in this work. The author is alone responsible for the following remarks, inasmuch as they represent his own conclusions, drawn from the making of practical daily forecasts, rather than those of anyone else.

1. The leading point in making forecasts is to determine which are the primary and which are the secondary weather forces, that is to say, whether the highs or the lows are to be regarded as dominating in the mechanism of the atmosphere. We have been forced to abandon the earlier view that the lows or storms are most important, and conclude that in forecasting the highs are always primary and the lows secondary. Many reasons can be given for this change of view. The forceful character of intensely developed storms have so impressed the public, and many students as well, with their characteristic features as to have secured for them undue consideration in the interpretation of the maps. Stormy weather, precipitation, high winds, local storms, and thunderstorms have been so associated with the low pressure that many were persuaded that the lows were the primary and the highs only a secondary feature of the weather. A whole literature, based upon the convectional theory of storms, has thus subordinated the highs to the lows. But if the highs depend upon local overheated areas which overflow and form the highs, then whole features of the general circulation are ignored and the accompanying minor effects in storms are exaggerated into primary causes. On the other hand, as a matter of fact, complete lows are formed without temperature gradients of importance; they exist without precipitation; they do not frequent the Tropics, where heat and rain most favor their formation; their insignificant size precludes the idea that their products are seen in the adjacent highs.

Our view is that the lows are mere appendages to the high areas, and these are built up in the general circulation which depends upon the temperature gradient between the equator and the poles, and thus have a sufficient and continuous source of supply for their large masses. The running down of the highs by gravitation causes gyratory lows to form along their periphery, as in tropical hurricanes, and especially between two adjacent highs where the countercurrents meet in the vortical trough or centralized storm, particularly in the middle latitudes. This is in harmony with the fact that the opposite sides of lows are of such different temperature, and that the precipitation is merely the waste product of the reduction of masses of air of different temperatures and vapor contents to the same physical state. The outcome of studies of cloud movements and the resulting knowledge of the general atmospheric currents lend great weight to this order of development. Such observations show that the upper strata are but slightly distorted from their average eastern drift except within about 2 miles of the ground. It is a principle of hydrodynamics that a fluid will not long move in a straight line, or even in an easy curve for a very long distance, without being thrown into a gyration upon encountering any obstacle, or at the least failure in the pressure gradients which are required for such movements. In the upper as in the lower atmosphere the temperature is constantly disturbing the normal north and south gradients, and the deflecting force of the rotating earth is prompt to take advantage of this variation. Hence the rapidly moving eastward upper strata are prone to swerve into a right-handed vortical movement in the northern middle latitudes, and then they burrow downward to the surface of the earth under the action of gravity, bringing cool, drying air in large masses of higher pressure, which necessarily flow out from the center of this circulation. The power behind the downward anticyclonic circulation of middle latitudes is the same as that which drives the trade winds, namely, the general tendency to equilibrium in the atmosphere. Its amount is measured by the difference in velocity of eastward movement in the upper and the lower strata. Without it the eastward drift would be very much more rapid than it now is. Such air must be disposed of and returned to the upper strata. The two adjacent highs throw out countercurrents which produce a vortex, to a large extent dynamic in its construction, that is to say, sustained by pressure transmitted hydrostatically from the high centers outward, and therefore *driven upward and compelled to rotate against the eastward-flowing strata into which it is injected.* The currents in the cumulus clouds strata show this, where the stream lines are soon wiped out at the distance of 2 miles or less above the ground, beyond which elevation the cyclone shows only a small distortion of the eastward streams. These lines of upward cyclonic discharge are perpetually renewed by the air driven outward from the highs, and they may therefore persist as long as the highs are maintained—that is, while the general circulation seeks a particular local downward discharge. This may properly be called a *stationary circulation*, since a similar flow at the same relative point in the atmosphere will give the same pressure, although the entire system of high and low drifts eastward in the middle latitudes. This is a much better word to describe the case than the *stationary waves* of Von Helmholtz or Max Margules, since the analogy of a *stationary wave* is very unlike this process, a wave being formed by transmission of energy through the same mass of material, a *stationary circulation* by the transfer of different material through the same region in an equal flow. The air flowing from the northwest toward the equator and from the southwest toward the poles in middle latitudes does not move in great sheets, as the general theory of Ferrel or Overbeck implies, but in immense detached masses, and these are chiefly concerned in building first the highs, and out of them the lows. The details of this interesting circulation are yet to be fully determined, especially the part the different strata play in forming it. At present the evidence is that the strata within 2 miles of the ground have most to do with it, the upper strata merely feeding the highs and receiving the discharge of the lows, but very little air passing directly from the top of a low into the top of a high.

The practical consequences of this view in forecasting are very important. The action of the high becomes the leading feature in determining the future conditions of the weather, and the lows are mere incidental or secondary consequences, however important to the public these may become. Therefore the track of a cyclone is along the edge of the high, combining the eastward drift with the advancing movement of the vortex as it is fed in from the fresh portions of the high. A West India hurricane moves westward in the westmoving tropical upper air, recurves around the edge of the great Atlantic high, and advances eastward in the mid-latitude eastmoving upper air, the low pressure being a symptom of this continuous stationary circulation, using the word stationary in its technical meaning given above.

Again, the rain areas are formed along the edges of the high, at a certain average distance from its center, the irregular patches occurring on the weather map being generally parts of such a formation. This is about the only rule in forecasting rain that is of real value and capable of serving on all occasions. Precipitation is apparently formed by the discharge of the cool upper air into the adjacent low stratum, the lowering of temperature by direct contact of masses of cool air with masses of warm moist air being evidently most efficient in producing the scattered rainfalls. Intimate mixture has some effect, radiation some, adiabatic cooling by expansion much, but in our judgment such direct contact cooling by the intermixture of large masses of air at different temperatures is the leading process, as evidenced by the data of the weather maps. This is especially vigorous in the eastward quadrants of the lows, where the northwest cold dry current is intimately mixing in discontinuous shreds with the warm moist atmosphere from the southeast, this formation of currents being a vortical product. No doubt the rising air cools by expansion, but it is probable that the flowing together of these two sheets of air in the stratum about 1 mile high is chiefly instrumental in effecting rainfall. Warm moist air rising upward against an overflowing cold sheet is the best possible condition for rainfall. The thunderstorms and local storms of summer are associated with the southeast quadrant merely because the counterflows from the adjacent highs meet together in this region. It is of course admitted that the latent heat derived from the condensation of vapor in the atmosphere greatly strengthens the formation of the cyclonic vortices in the low areas and intensifies the violence of storms, but it is hardly a necessary feature in their formation, as numerous examples on the weather maps testify.

The primary principle of forecasting is, therefore: *Subordinate all weather features to the high areas, determine the movements and the action of the highs, deducing the effect of these upon each other in the counterflow and along the isolated periphery.*

2. The next important principle in forecasting is the mode of determining the movements of the high-pressure areas. This depends upon two general systems of conditions: (1) The continental and oceanic areas, and (2) the configuration of the general circulation about the North American continent. The details must be learned by examination of the charts, viewed in their annual changes. In the winter the continent by its effect upon radiation, with the sun in the southern hemisphere, tends to build up strong, cold, high-pressure areas, and these are propagated south and eastward, in the northern or the southern circuits, as heretofore explained. In the summer the continent tends to build feeble, warm, low-pressure areas in the interior, with high areas bordering the coast districts, so that the circulation is from the oceans to the interior. The difference in the interpretation of the isobars is important, because a summer cyclonic circulation near the Rocky Mountains means little in the way of a general storm, though local storms, tornadoes, and thunderstorms may be produced. But in the winter the formation of a cyclonic circulation on the eastern side of the divide of the mountains is very likely to reach the ocean before dissipation, while in summer many such storms die out in the Lake region and the upper St. Lawrence Valley.

The movement of highs generally is decided by the peculiar intraction that exists between the great eastward drift in middle latitudes and the calm or stationary high that tends to build in the subtropical belt. If a high is caught firmly in the eastward drift, it will move over the northern circuit toward the great permanent cyclone of the North Atlantic Ocean; if it is needed to build into the tropical high-pressure belt, it will move in the southern circuit to the Gulf States. One of the important problems of practical meteorology is to determine when the highs will take these courses, respectively. On reaching the Atlantic coast a double uncertainty overtakes the high movements—that is, they may settle from the north to the south, especially in summer, or they may be drawn from the south northward, particularly in the winter. During seasons of stagnant circulation they may linger many days upon the coast line, with a slight movement northward or southward. The second great principle is: *Determine from a knowledge of the general circulation the movement of the high areas in the northern or the southern circuits, and along the Atlantic coast line, as specified by the appearance of a given map.*

3. The next fundamental point to have in mind is the rapidity of the eastward drift, especially in the northern circuit. This is subjected to a succession of accelerations and retardations, rapid movements, and stagnant conditions, which are always very puzzling to the forecaster. It is clear that these must also be referred to the circulation of the upper strata to some extent, but our knowledge of this subject is so imperfect that no final statements can now be made regarding it. We may hope by patient observations of the cloud motions to ultimately bring this also within our understanding.

LONG-RANGE FORECASTING.

The advantages that would be derived from an ability to forecast weather conditions for considerable intervals in advance of occurrence are very obvious, especially to provide successful forecasts of the seasonal variations from year to year. Many attempts have been made to accomplish this result, but usually in so unscientific a way as to have discredited such efforts and to have brought the entire subject into disrepute. On this account the official forecasts of the Weather Bureau have been carefully confined to periods of forty-eight hours or less, and no definite forecasts have ever been published for the seasons of the year in advance. In truth, the difficulties to be overcome in order to make such forecasts scientifically are enormous, and they have not yet yielded to some very persistent labor. It is easily seen that a successful long-range forecast can be based only upon an accurate understanding of the laws of the general and also the local circulations of the upper and lower strata of the air as modified by the continents and the oceans; likewise it is necessary to know the exact relation that the solar energy bears to these atmospheric movements. Until the physical laws are fully in our possession and the result is such as to demonstrate the impossibility of seasonal weather predictions, it is allowable to indulge the hope that forecasts may some time be made to extend beyond the two-day limit now set.

To make an attack of importance upon this obscure region of meteorology it is first necessary to learn how to classify weather conditions in order to study them properly, and this means the detection of all the fundamental periods. Besides the diurnal period depending upon the rotation of the earth on its axis and the annual period due to the revolution of the earth in its orbit around the sun there must be yet others which depend upon the action of the sun itself. One of these is the rotation of the sun on its axis, another the slow congestion of the sun's material in the 11-year period, and in the subordinate 2¾-year period, and there may be also very long periods which can not be considered in this connection. It is clear that the calendar months, according to which our meteorological data are commonly collected, for which intervals the means are taken, have no natural periodic relation to the underlying phenomena, and that the customary method of operation tends merely to conceal any natural laws that may really exist in the periodic repetition of weather conditions. Hence it is of primary importance to discover an accurate fundamental period to substitute for the calendar-month system.

As the result of much work on the variations of the terrestrial magnetic field, it is concluded that such a period exists, dependent upon the rotation of the sun on its axis, giving a normal curve which tends to repeat itself in 26.67928 days. The curve is shown on Chart 18, and the following ephemeris gives the dates of the beginning of the same curve for the first period in each year for the years 1840–1899, inclusive. Other dates can be readily found throughout any year by adding 26.68 days successively to the January date of the given year.

Ephemeris of the synodic rotation of the sun.

[Period, 26.67928 days; epoch, June 13.72, 1887.]

Year.	Date.	Year.	Date.	Year.	Date.
1840	Jan. 16.87	1860	Jan. 21.99	1880	Jan. 27.11
1841	Jan. 24.38	1861	Jan. 2.82	1881	Jan. 7.94
1842	Jan. 6.21	1862	Jan. 11.33	1882	Jan. 16.45
1843	Jan. 14.72	1863	Jan. 19.84	1883	Jan. 24.96
1844	Jan. 23.23	1864	Jan. 1.67	1884	Jan. 6.79
1845	Jan. 4.06	1865	Jan. 9.18	1885	Jan. 14.30
1846	Jan. 12.57	1866	Jan. 17.69	1886	Jan. 22.81
1847	Jan. 21.08	1867	Jan. 26.20	1887	Jan. 4.64
1848	Jan. 2.91	1868	Jan. 8.03	1888	Jan. 13.15
1849	Jan. 10.42	1869	Jan. 15.54	1889	Jan. 20.66
1850	Jan. 18.93	1870	Jan. 24.05	1890	Jan. 2.49
1851	Jan. 27.44	1871	Jan. 5.88	1891	Jan. 11.00
1852	Jan. 9.27	1872	Jan. 14.39	1892	Jan. 19.51
1853	Jan. 16.78	1873	Jan. 21.90	1893	Jan. 27.02
1854	Jan. 25.29	1874	Jan. 3.73	1894	Jan. 8.85
1855	Jan. 7.12	1875	Jan. 12.24	1895	Jan. 17.36
1856	Jan. 15.63	1876	Jan. 20.75	1896	Jan. 25.87
1857	Jan. 23.14	1877	Jan. 1.59	1897	Jan. 6.70
1858	Jan. 4.97	1878	Jan. 10.09	1898	Jan. 15.21
1859	Jan. 13.48	1879	Jan. 18.60	1899	Jan. 23.72

Up to this point the investigation was not really difficult, but on applying the curve to current meteorological and magnetic phenomena a very surprising fact emerged into view for consideration. The observations during certain months followed the curve in the direct form given above and in other months in the form derived by inverting this curve on its long axis. There was also a certain looseness attending the matching of the normal curve to the individual repetitions as recorded in the observations, which sometimes made it difficult to decide whether the direct or inverse type was really represented, and this irregularity seemed to occur in a lawless way. It is easy to see that some of the causes at work to produce that effect are (1) the spasmodic and irregular action of the sun itself in producing an external field of magnetic force; (2) the variable action of the earth's atmosphere in forming the convection currents and the corresponding highs and lows; (3) the unsteady eastward drift; and, (4) the unknown forces of absorption and radiation at work in the atmosphere. Nevertheless, in hope of discovering the law of such reversals, the magnetic horizontal forces observed since the year 1841 were transferred from the published reports to curves plotted according to the periods of the ephemeris. Then the normal curve was matched with each period as impartially as possible and in such a manner as to leave the judgment unprejudiced, being repeated on different occasions, and marked D for direct type and I for inverse type. Then the number of D's in each of the 14 periods was counted up for the years 1841–1894, inclusive, and the result is recorded in the numbers as the bottom of Chart 19. This shows the tendency for the direct form to prevail in different portions of the year, and the inverse type is merely complementary to it. The representative line is evidently a semiannual periodic sine curve, repeated twice annually, and its relation to the sun's and the earth's equators is shown, these being placed in the position assumed in June for an observer looking at the sun from the earth. On Chart 20 the same curve is shown in its relations to the fundamental planes, Ecliptic K, Sun's Equator S, Earth's Equator E, wherein is seen the astronomical triangle and the nodal lines as derived from astronomical data. The direct type only is represented on the chart, but the inverse type bears a counterpart relation from right to left. The positions where these curves cut the ecliptic show the points where the two types are evenly balanced in a sort of penumbra. The solar force acts strongly enough at right angles and parallel to the solar axis to impress its type upon the terrestrial field; in the regions of transition the type is less clearly defined. The transition dates are near February 1, April 20, July 15, and October 15, on the average. The fact that this peculiar phenomenon occurs in terrestrial magnetic and also meteorological phenomena is very important. It implies that the storms of the northwest generate in an order influenced by the polar magnetic force from the sun.

It is necessary only to remark that the types appear to be determined

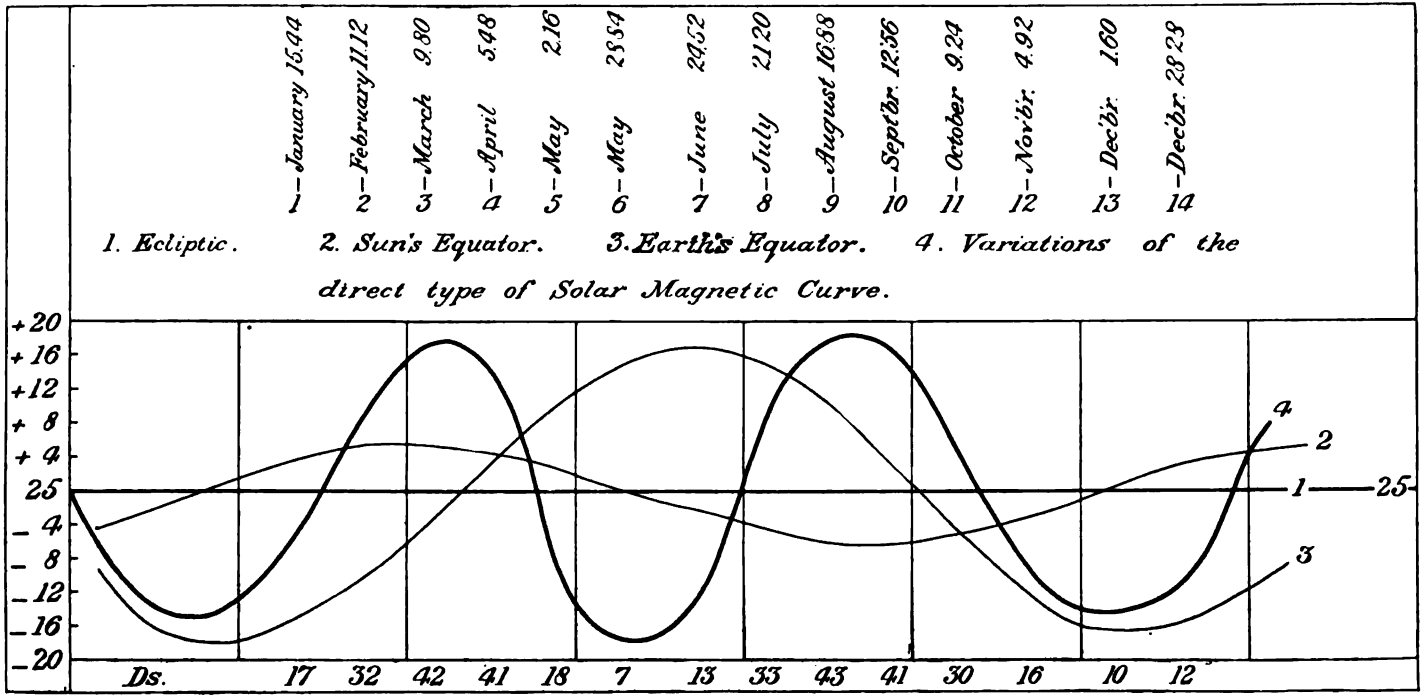

Chart 19.—Relative number of the direct type occurring annually, showing the semiannual periodic inversion. From the magnetic data 1841–1894.

by the position of the sun's axis projected on the ecliptic, the axis of type direct being perpendicular, and that of type inverse the parallel to that line. The physics involved in this relation can not here be given, but the main facts are evident enough: (1) We have therefore obtained a period of rotation for the sun that works without sliding for over fifty years; (2) also a well-formed curve, which, on the average, represents

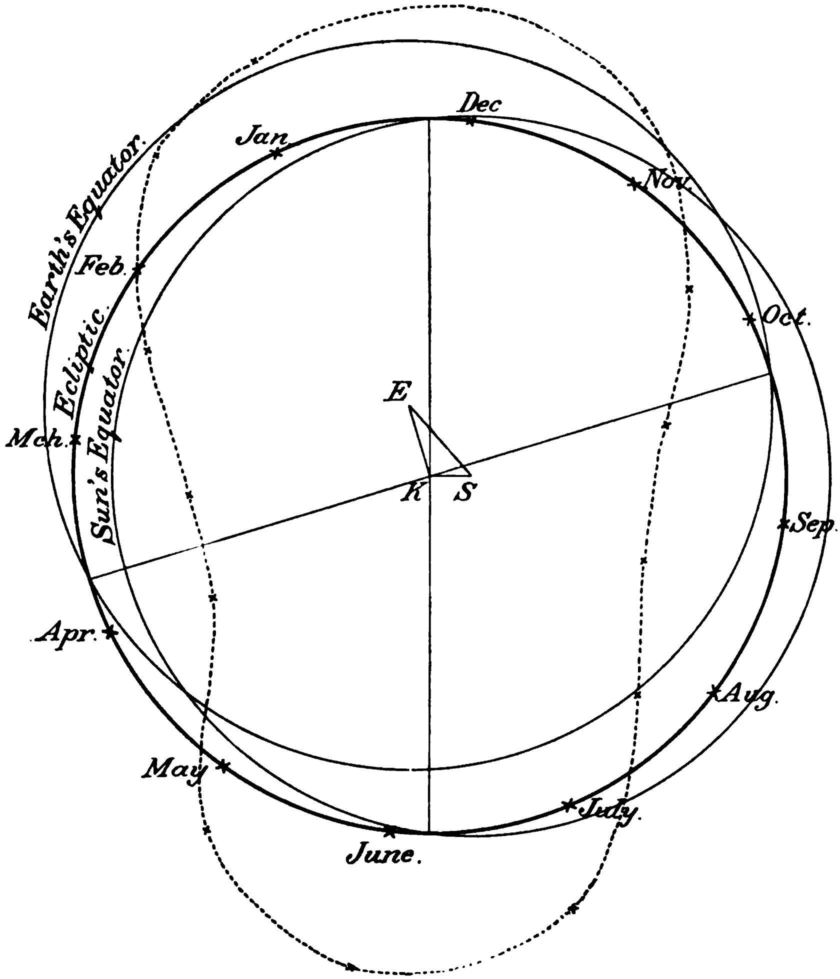

Chart 20.—Semiannual period in the inversion of the direct type of the solar magnetic curve.

terrestrial magnetic observations for this interval, and meteorological observations for at least twenty years; and (3) the peculiar law of inversion is such that the direct type prevails from about February 1 to April 20 and from July 15 to October 15; while the inverse type holds for the intervals April 20 to July 15 and October 15 to February 1.

We may therefore conclude that for a first approximation our process of long-range forecasting should be as follows: (1) In any year find the dates of beginning of the normal curves from the ephemeris; (2) classify the data as direct or inverse as far as possible within the dates above determined for the maximum of D and I types; (3) for any given day read the slope of the curve as shown by the normal period in the extreme northwest, that is, in western Canada, or in the Dakotas, counted as one day elapsed; (4) allow as far as possible for the eastern drift in the northern or the southern circuits to any station for which forecasts are required. These are the first definite rules for scientific long-range forecasts; but considering the many elements of the problem yet undetermined, it is hoped that no one will expect too much of them, or be discouraged by failures.

SUMMARY.

A brief summary of the scheme of meteorological thought herewith presented can now be given: (1) The general circulation of the atmosphere has a downward component near the poles where the northward upper stratum returns into the lower southward current, its power consisting in slowing down the rapid eastward drift by diverting it into descending anticyclonic vortices; (2) these are localized upon the continents, chiefly in winter, by reason of the action of the land areas being colder than the oceans, wherefore highs tend to form in western Canada especially during that season; (3) the entrance of the earth into longitudes of the sun having a stronger magnetic field lowers the temperature in this region, and thus assists the tendency to form high areas at definite dates in the general subpolar circulation, it being more pronounced on the North American continent than elsewhere in the same high latitudes by reason of the presence of the magnetic pole near that place; (4) these highs drift southward and eastward within the great eastward upper current, being still fed by the general circulation, which itself is sustained from the tropical zones and continues to discharge downward into the highs by means of an anticyclonic stationary system of streams; (5) between successive highs is formed a low with cyclonic circulation, which, under hydrostatic pressure, aided by convectional vertical components of warmer air, drives the air in stream lines back into the upper strata, there to be aimlessly destroyed in the rapid eastward currents; (6) the convective action in cyclones derived from local temperature and the latent heat of condensation of vapor in precipitation is an important incident, assisting gyratory vortex action, but after all only a secondary phenomenon; (7) this view admits the validity of Ferrel's analytical solution (also Overbeck's) of the *general* circulation of the atmosphere, but concludes that it is not strictly applicable to the local mid-latitude cyclones; that the general cyclone of the poles and the local cyclone with anticyclone surrounding it are not so parallel in theory as was supposed in the formulæ. On the other hand, the lows are not eddies in the upper currents, but more properly the highs are the eddies; actually they are stationary downward circulations in deflecting the direction of the upper into the lower strata, and the lows are secondary effects derived from these under the impelling forces of gravity and hydrostatic pressure. This explanation gives to the entire machinery of the atmosphere, it is believed, a logical and harmonious operation, and it certainly avoids some of the difficulties that are now felt by meteorologists.

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